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THE ACQUISITION, EXTINCTION, AND SPONTANEOUS RECOVERY OF A CONDITIONED OPERANT RESPONSE

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A great deal of psychological research has been devoted to determining how and under what conditions modifications of an organism's behavior take place. 'Learning' is the term ordinarily applied to the progressive changes observed in behavior upon repeated presentation of a stimulus situation which is accompanied by reinforcement. Learning curves which express such changes from one stimulation to the next have been presented in terms of errors, time, frequency, or percentage of occurrence of some standard response. Attempts to draw generalized descriptions of behavior modification from these curves have been complicated to a large extent by the lack of any good correlations between measurements taken under widely different experimental circumstances. While each description may involve certain factors which are generally agreed to justify its inclusion under the term 'learning,' the difficulty of comparison with other descriptions arises because of the existence, in each experimental situation, of certain other unevaluated factors. It is reasonable to suppose that the best understanding of this type of behavior may be derived from a situation which satisfies the conditions of 'learning,' and which is simplified to the extent that the number of controlling variables is reduced to a minimum.

Historically, such a restriction of conditions has been employed in experiments on conditioned reflexes. The unconditioned stimulus has generally been chosen for its ability to evoke a response involving a single muscle group or a simple glandular secretion. In some cases the response has been further restricted by surgical operation performed on the experimental animal. Carried to an extreme degree, operation may come to entail an artificial condition which does not produce results directly consistent with the behavior of the unrestricted organism. The question of how much or how little restriction is necessary in studies of reflexes is discussed by Skinner (**16**, **18**). His conclusion is that the level of restriction is best determined by consistency and reproducibility of the function which represents the relation between stimulus and response.

Another type of stimulus-response correlation which has been studied has been variously named 'trial-and-error behavior' (**19**), 'problem-solving' (*cf.* **12**), 'Thorndikian reaction' (**20**), and 'operant behavior' (**18**). Skinner has defined it most clearly (**18**) and has pointed out that there are seven differences between the operations to be performed in conditioning this type of reflex and the ordinary Pavlovian type (**17**). Chief of these differences is the fact that no external stimulus originally elicits the reflex which is to be modified. The operant reflex, therefore, must possess a certain initial strength in order for the response to occur once, whereas the Pavlovian reflex does not require this condition. The important thing in operant behavior is the conditioned response (*e.g.*, pressing a lever), since this itself produces the reinforcing state of affairs; in 'respondent' behavior, on the other hand, the conditioned stimulus is the important factor, and the response to it (*e.g.*, pricking up the ears) usually disappears.

According to Hilgard (**4**), the class to which any description of learning belongs is determined by the responses which are *measured*, and not by the responses which actually take place. There may be in the Pavlovian experiment a response, such as the dog's looking toward the food pan, which is

analogous to the rat's pressing the lever. It may also be true that the rat salivates in the presence of the lever. The essential differences between the two types would then depend upon the fact that in each situation one response is measured to the exclusion of the other. Such an analysis seems to mean that both types of conditioning may take place in these experiments. The question of the fundamental distinctness of the two types has probably not been answered, although some worthwhile attempts have been made [*cf.*, for example, the recent statement of de Montpellier (**3**)].

Without disregarding difficulties inherent in the problem it is possible to study the course of 'learning' or conditioning under controlled conditions. For the purposes of experimental analysis, all that is important is the presence of certain variables which have been found to determine the conditioning process. Among these factors are 'drive' and the presence of conditioned and unconditioned stimuli, together with their interrelated temporal effects. The necessity for restriction of behavior to a level of reproducibility has already been mentioned.

Even in the studies of Pavlovian conditioned reflexes, where restriction of response is most clearly applied, a further condition is desirable. This is in regard to the units employed to measure the changes in behavior. Comparisons and eventual correlations with other sets of data are facilitated by the use of units of known physical dimensions. In addition, any confusion concerning what is being measured is avoided. Such units of measurement as time, distance, mass, and others derived from these, are fundamental to all science, and facilitate the correlation of the data of several disciplines. The employment of arbitrary units such as percentage of appearance of response makes difficult the interpretation of data as well as their correlation with other observations.

The problem to be investigated in the present research involves measurement of the acquisition, extinction, and spontaneous recovery of a conditioned response in the white rat. This requires the choice of some aspect of the total response which can be restricted to a point where reproducible

data are obtainable. Furthermore, we feel that the observations should be expressed in directly measurable units of a continuous scale. The measure which we have used and which seems to meet these requirements involves the determination of a 'latent period.'

Throughout the course of the determinations our experiments were guided by the quantitative requirement of a formal hypothesis as to the nature of conditioning. The hypothesis is considered in detail in a later section of the paper. In that section we present a discussion of the relation of data and theory, and we consider the advantages of the model which we have kept in mind.

Experimental

Design of the Experiment

For the purpose of this experiment we used the simple runway shown in Fig. 1, which requires of the rat the response of running to a food box. This behavior may be considered a conditioned response of the operant type (**17**), the conditioned stimulus for which is the change in environmental energies produced by the opening of a door in front of the starting-box. The running behavior is terminated at the food-box by stimulation from the food (unconditioned stimulus) and the eventual unconditioned response, eating.

The conditioned response can be observed and measured in several of its aspects. The most convenient measure seems to be the interval of time between the presentation of the conditioned stimulus and the occurrence of the conditioned response. This interval may be called the *latent period* of response and it has been found to vary in a regular manner under the conditions of this experiment. Another possible measure which we might have used is the time required to traverse the runway. This measure has been employed by Hull (**6**) and Miller and Stevenson (**9**), but in our experiment the runway-distance is so short as to make this a relatively insensitive measure. The use of the term 'latent period' in the present research must be considered nothing more than an analogy with its use in certain physiological experiments.

Practically, the term seems justified by the fact that, during this interval, aspects of behavior immediately relevant to the running response are not observed.

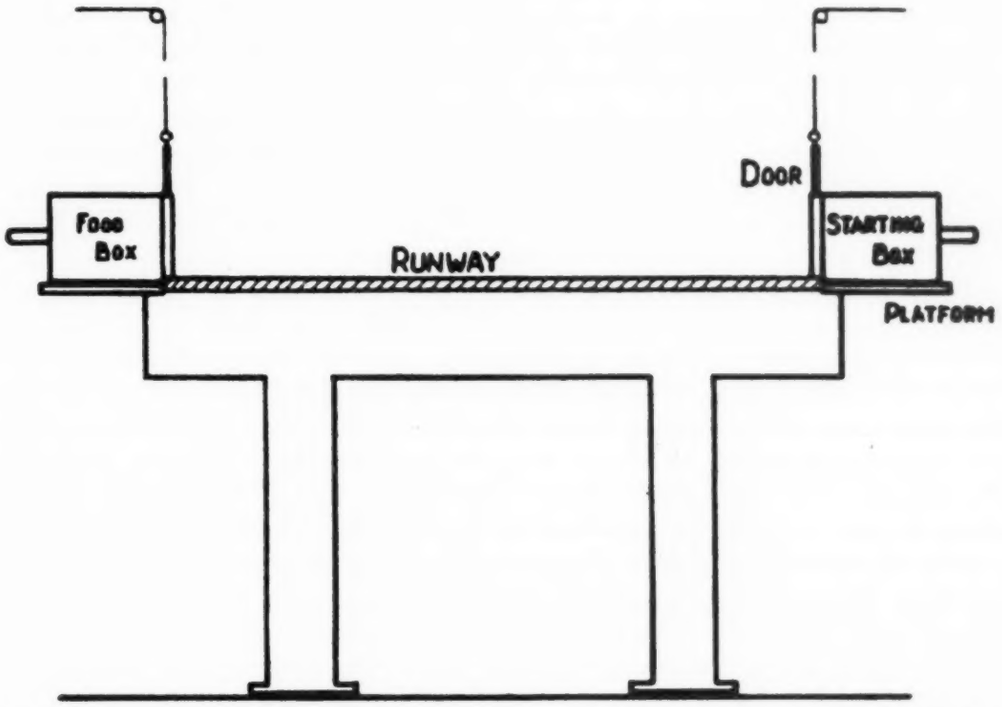

FIG. 1. Diagram of the apparatus used in these experiments. The animal runs from the starting box to the food box by way of the runway.

In the experiments to be reported an attempt was made to keep all extraneous variables constant from trial to trial. The unconditioned stimulus was maintained constant by using uniform particles of food, small enough so that the consumption of fifteen of them by the rat during the experiment did not materially affect the strength of the hunger drive. The time between the response and the next presentation of the conditioned stimulus was kept a definite interval throughout, thereby assuring equally spaced trial units. The conditioned stimulus and other parts of the apparatus remained unchanged during the course of the experiment. Accordingly the measures obtained can be expected to represent changes in strength of response (*a*) during fifteen reinforced trials (acquisition), (*b*) during five non-reinforced trials (extinction), and (*c*) after certain intervals of time following a practically complete initial extinction (spontaneous recovery).

Apparatus and General Procedure

A diagram of the apparatus used in these experiments is shown in Figure 1. The equipment consists of a simple elevated runway three feet long and three-quarters of an inch wide. At each end of this runway is a small platform, 6 inches by 8 inches, on which can be placed either the starting box or the food box. The latter boxes are interchangeable, and in their outside dimensions measure 6 inches wide, 6½ inches high, and 7½ inches long. They are open in front and covered on top by a wire screen. Attached to the back of each box is a handle by means of which the experimenter can carry the box from one end of the runway to the other. In front of each platform is a small door which serves to close the front of the appropriate box. The experimenter can raise and lower each door quietly by means of twine passing over pulleys out of sight of the animal.

The entire apparatus, with the exception of the outer ends of the platforms and boxes, is enclosed in a sturdy framework, 2 feet wide, 4 feet long, and 4½ feet high, covered on the sides and top with cheesecloth. This structure is illuminated from within by a 25-watt light hanging about a foot above and in front of the food-box. The framework with its cheesecloth sides serves as a relatively effective one-way screen and eliminates important visual cues from the experimenter's movements during the trial periods. The experimental room is located in a part of the building which is ordinarily quiet at night, the time when the experiments were conducted.

The experimental food was prepared by cutting pellets of dog chow, the regular rat colony diet, into small pieces weighing about 0.04 grams apiece. According to Skinner's (13) results, the drive of hungry rats remains at a constant level during the consumption of about 100 pellets (5 grams). In our experiments, since each rat consumed about 0.6 grams during the fifteen reinforced trials, it is reasonable to suppose that the drive was insignificantly diminished by reinforcement.

The animals used in these experiments were thirty-six male white rats of an inbred Wistar strain. All of these animals had been reared from birth in ordinary living cages, and none had been used previously for experimental work.

Each rat was given four days of preliminary habituation to the experimental room and the experimenter. During this time none of the animals had any experience with the runway or with the starting position used in the experiment. On each training day the rat was allowed to run for ten minutes, without reinforcement of any sort, on some units of an elevated maze which closely resembled the experimental runway. He was then placed in a cage for a few minutes, after which he was permitted to eat for twenty minutes in one of the experimental boxes (used interchangeably during the experiment as food- or starting-box). This was the only food the animal received during the habituation period. On the final day the time for eating was shortened to twelve minutes.

Acquisition

Twenty-one rats of average age 128 days, constituting what will hereafter be referred to as Group A, were used in determining the course of acquisition. Actually, thirty-four rats were employed in all. Eight of these were discarded when they failed to leave the starting-box in five minutes on the initial trial of acquisition. It is believed that this arbi-

trarily imposed criterion served to eliminate animals which reacted unfavorably, perhaps emotionally, towards the experimental situation. Acquisition was measured in five other rats, but the results were not included because the animals required fewer than six trials for extinction. The reasons for this extinction criterion are discussed in a later section.

The experiment was conducted in the following manner: On any one experimental day, a rat was taken directly from its living cage and placed in the starting-box on the platform of Fig. 1, the door remaining closed. A small piece of food was placed in the food-box, with door open, at the opposite end of the runway. The starting door was now opened and a stop-watch started. The watch was stopped when the animal's body, exclusive of tail, had left the box and passed a fixed mark 4 inches from the starting-box. This interval was recorded as the latent period of response.

The animal traversed the runway, entered the food-box, and found the food in its customary position within the box. The narrowness of the runway (width 3/4 inch) practically excluded the occurrence of retracings, so that, once started, the animal continued to run the length of the runway. (Only two or three times during the experiments did an animal turn back after having crossed the starting mark. In these cases the watch was started again immediately, and the entire time between the opening of the door and the second crossing of the mark was recorded. These determinations may involve a small error, but since the runs occurred in the beginning of acquisition the percentage effect is slight.) With the animal in the food-box, the experimenter closed the door and proceeded to record the time shown on the watch. When the animal had finished eating, usually in about twenty seconds, he was carried in the box back to the starting position, and the former starting-box, with a pellet of food in it, was placed in the food-box position. Seventy-five seconds after the arrival of the animal at the food-box the experimenter again opened the starting door, and the second trial was begun. This procedure was continued for fifteen trials.

It is to be noted that the rat always started from the same

end of the runway and ran in the same direction, that is, toward the more brightly illuminated part of the apparatus. Since the starting door, the opening of which signalizes the conditioned stimulus, was attached to the end of the runway, this also remained constant from one trial to the next. The starting- and food-boxes, identical in structure and appearance, were interchanged between trials. Preliminary experiments with the apparatus convinced the authors that alternatives to this procedure, such as picking the rat up by hand, or rotating the runway, effected disturbances in the animal's behavior. No detectable disturbance could be observed under the procedure finally employed.

The average logarithms of the latent period as a function of the number of trials in acquisition are presented in Table 1, together with the average deviations of log latent period. The values for each trial of acquisition were obtained by averaging results from the twenty-one rats in Group A. It will be readily realized that these averages represent the log geometric average of the data on each trial.

The logarithms of the latent period have been averaged because of the fact that the distribution of latent periods at any trial is not normal, but skewed in the direction of the longer latent periods. The distribution for log latent period, however, is approximately normal. Some interesting conclusions with regard to variability follow from this initial observation and from the behavior of variability on successive trials. It will be seen in Table 1 that, throughout acquisition, the variability of log latent period ($A.D._{\log P}$) is approximately constant, a finding which indicates that the upper limit of variability is a constant multiple of the mean; the mean in turn is the same multiple of the lower limit. Thus, in the early stages of acquisition a group of animals with a geometric mean latent period of 20 seconds may vary frequently in latent period between 20 and 40 seconds; on the other hand, they will vary just as frequently between the limits 10 to 20 seconds. Similarly, in the later stages of acquisition the same animals, having achieved an average latency of 4 seconds, will vary as frequently between 4 and 8

TABLE 1

THE DATA ON ACQUISITION, EXTINCTION AND SPONTANEOUS RECOVERY, TOGETHER WITH THE VARIABILITY VALUES OF LOG_{10} LATENT PERIOD ($A.D._{\log P}$)

Process	Interval after Extinction (min.)	Trial	Log_{10} Latent Period	$A.D._{\log P}$	Latent Period (Geometric Mean) (sec.)
Acquisition		1	1.85	0.26	71.0
		2	1.22	.23	17.0
		3	0.98	.36	9.6
		4	0.81	.28	6.5
		5	0.97	.31	9.3
		6	0.86	.33	7.2
		7	0.83	.30	6.8
		8	0.67	.26	4.7
		9	0.74	.27	5.5
		10	0.66	.34	4.6
		11	0.49	.29	3.1
		12	0.48	.35	3.0
		13	0.51	.34	3.2
		14	0.49	.36	3.1
		15	0.45	.33	2.8
Extinction (Group A)		1	0.41	.32	2.6
		2	0.74	.36	5.5
		3	0.97	.40	9.3
		4	1.23	.54	17.0
		5	1.35	.31	22.0
Extinction (Group B)		1	0.38	.25	2.4
		2	0.73	.42	5.4
		3	0.93	.41	8.5
		4	1.24	.30	17.0
		5	1.30	.37	20.0
Spontaneous Recovery	1		2.01	.12	102.0
	3		1.81	.09	65.0
	6		1.57	.09	37.0
	10		1.54	.17	35.0

seconds or 2 and 4 seconds as they did formerly between the limits 10 and 20 or 20 and 40. Crozier (1) and Crozier and Hoagland (2) have advanced a number of arguments in favor of treating variability as a functionally determined aspect of the experimental conditions, and the argument is clearly applicable in the present circumstances.

A curve of acquisition, with average log latent period of response plotted against trial, is shown in Fig. 2. Starting from a log latent period value of 1.85 (71 seconds), the curve drops sharply at first, and then more gradually, to reach a

log value of 0.45 (2.8 seconds) at the final trial. Thus the latent period of the response undergoes a change during acquisition which is of the order of 25 to 1. If we disregard

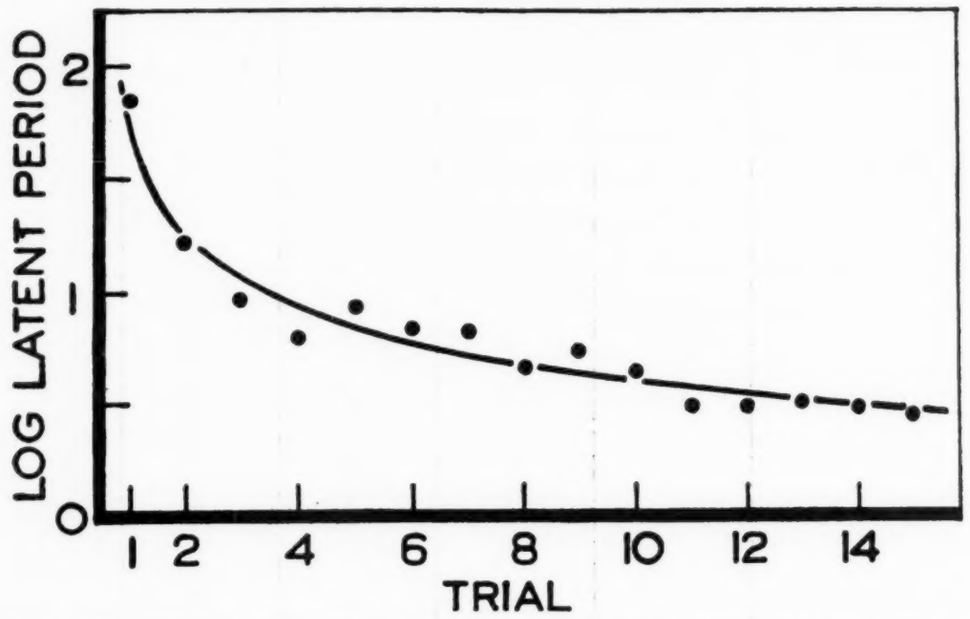

FIG. 2. The curve of acquisition. The logarithm of the latent period is plotted as a function of the number of reinforced trials for twenty-one rats.

the first trial of acquisition, the range reduces to 9 to 1, a value similar to that found in extinction but with direction of change reversed. The change in slope of the acquisition curve is such that a final level is approached after about ten trials.

Extinction

In addition to twenty-one rats of Group A, twenty male white rats of average age 143 days, which will be referred to as Group B, were used to determine changes in latent period during experimental extinction. Five of these animals had taken part in the experiments on Group A and were later included in Group B. More than a month elapsed between the two procedures and it is probable that the animals' experience in the earlier experiments had little influence on their later performance. Measurement of extinction was performed on seven additional animals, five under the procedure used with Group A and two under the procedure of Group B. The results of these seven animals were not in-

cluded because the number of trials required for extinction was fewer than six in each case. The criterion of six trials was set up in order to provide a curve based on five points. The requirement of five points is arbitrary, of course, but it has the advantage of providing a sufficient number of points to establish a definitive relation and at the same time eliminates the necessity of averaging the irregular latent period values which occur as extinction approaches completion.

Group B rats received the same preliminary training as those of Group A and were used in determinations of spontaneous recovery. The acquisition trials of Group B were not recorded, since for convenience they were spread over two experimental days. On the first of these, the animal was given seven reinforced trials and was then allowed to eat for twelve minutes in the food-box. At the next experimental session, the rat was given from three to twelve reinforced trials, in each case as many as were needed to obtain a response, measured in three consecutive trials, with a latent period of less than five seconds. This criterion assured a level of acquisition which was comparable with the value of the final acquisition trial of Group A. It is probable that this difference in procedure with Group B introduced no anomalous effects. At any rate it is certain that the extinction curves for both groups are similar, a finding which might not be expected if significant differences had entered into the original acquisition.

For both groups of animals, the first trial of extinction followed the final acquisition trial at the usual 75-second interval. During extinction all conditions remained the same as when acquisition was being measured, with the exception that no food was placed in the food-box. The trials were continued until the response failed to appear after 3 minutes. The 3-minute criterion was chosen because preliminary observations on several rats showed that if the response failed to appear in this interval it did not appear in a uniform manner for a longer period. For all practical purposes extinction may be considered complete in this time.

The mean log latent period values were computed for five

trials. Most of the animals reached the 3-minute criterion on the sixth trial, but several required a greater number. Averaging results beyond the fifth trial would have required either the inclusion of the criterion trial (which involves an indeterminate numerical value), or the use of determinations on a smaller number of animals. Both these procedures introduce undesirable features into the computation of average values.[1] The values as calculated for the fifth non-reinforced trial are derived from twenty-one animals in Group A and the twenty in Group B and represent a point at which the extinction process is approaching completion.

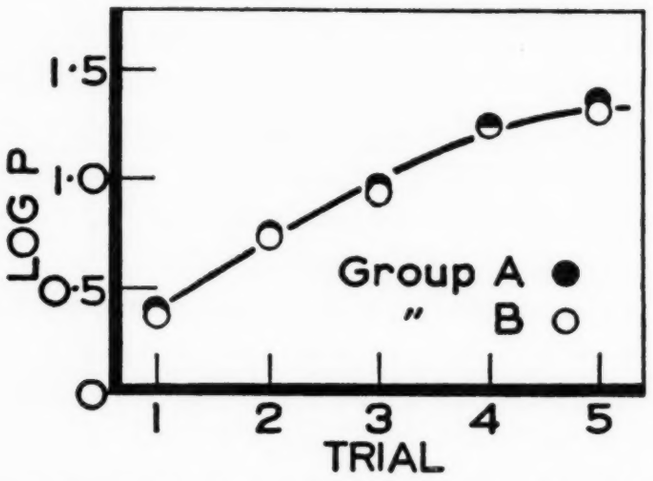

FIG. 3. The curve of extinction for two groups of animals. Group A contains twenty-one rats; Group B, twenty.

Figure 3 represents the curve of extinction for both groups. The log latent period of response starts at a level of about 0.41 (2.6 seconds), a value consistent with Group A's value of 0.45 for the immediately preceding trial (the fifteenth of acquisition). From this initial point the curve rises with a gradually decreasing slope to a log latent period value of 1.33 (21 seconds) at the fifth non-reinforced trial. Thus we see that five trials of non-reinforcement effect a nine-fold change in the latent period of the conditioned response. The close agreement between the values obtained from the two groups of rats gives an empirical measure of the reproducibility of the results.

[1] The Vincent method of computation was not used, since it is not adapted to curves which approach a final steady level. Further, it seemed to the authors to give rise to a new and essentially arbitrary independent variable.

Spontaneous Recovery

The twenty animals of Group B were used to measure spontaneous recovery of the conditioned response after extinction. The latent period of response was measured with four sets of five animals each, and any single set of animals was used on only one of the four recovery intervals investigated. By this means we took care that the determination with any rat should not be influenced by previous measurements of spontaneous recovery.

When the process of experimental extinction in a given animal had reached the three-minute latent period level, the door in front of the starting-box was closed for the duration of one of the selected recovery intervals. The condition existing under these circumstances resembles the period of no stimulation which is present in the spontaneous recovery of Pavlovian conditioned reflexes (**10**). At the end of the particular interval chosen for study, the door was raised and the stop-watch started. The latent period which was recorded in this way gives a measure of the spontaneous recovery of the response.

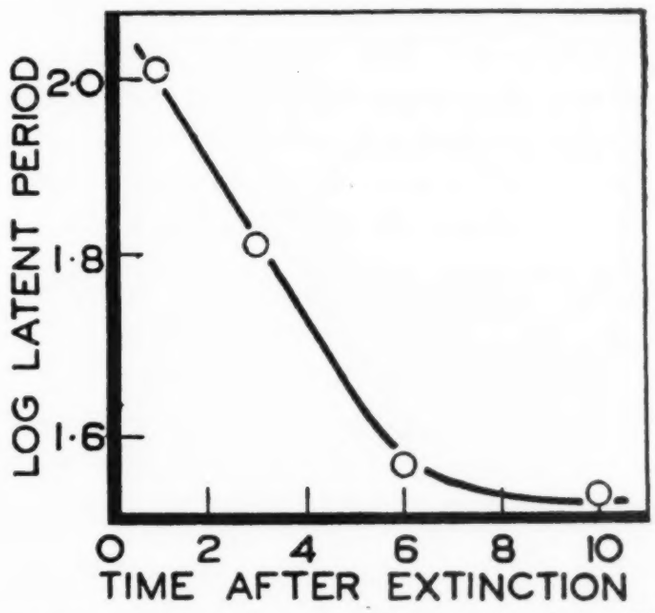

FIG. 4. Spontaneous recovery: the logarithm of the latent period as a function of length of interval after extinction. Each point represents determinations on five rats.

Spontaneous recovery of the response following extinction to a criterion of 3 minutes of no response is shown in Fig. 4

where each point represents the average log latent period obtained with five rats. After an interval of one minute the response has recovered sufficiently to have a log latent period value of 2.01 (103 seconds). As the interval is made longer the rate of recovery becomes proportionately less, so that after a 10-minute interval the log latent period of the response is 1.54 (35 seconds). Apparently the greatest degree of recovery takes place within the first 3 minutes after extinction. Moreover, the entire amount is relatively not great, for after 10 minutes the response is still far from the value which represents complete recovery. The question as to whether long time intervals will allow for complete recovery remains to be investigated, but the present results are significant in showing that spontaneous recovery takes place rapidly within the first few minutes after extinction.

Discussion

A Consideration of Results

The results which have been presented constitute a description of changes in latent period of response under the three conditions of reinforcement, non-reinforcement, and spontaneous recovery. The type of behavior studied is described by the paradigm employed by Skinner (17) to represent operant conditioning:

$$S_0 — R_0 \rightarrow S_1 — R_1.$$

In the situation employed, S_0 is the complex of stimuli (visual, tactual, etc.) arising from the front of the starting-box and the maze when the door is opened. R_0 is the reaction of traversing the runway, at first 'emitted' and then reinforced by the presence of the strong reflex S_1 (food) — R_1 (eating).[2] Certain obvious differences in technique between

[2] Professor Skinner (personal communication) thinks of the door movement in this experiment as comparable to his conditioned discriminative stimulus. If this be true our results are not comparable to his in the matter of extinction to such a stimulus (18). He failed to find any orderly change in latent period under these conditions, while we obtained orderly changes in acquisition and spontaneous recovery as well as extinction. At some later time it will probably be necessary to test for latency in the absence of the door.

this experiment and Skinner's make possible the control of trial intervals and of drive strength.

If we keep in mind the differences in the methods of presentation, it may be seen that the curve of acquisition here shown is similar in general outline to those found by Thorndike (**19**) in his study of trial-and-error behavior. The time required for his cats to leave the boxes was initially great, and subject to large individual variations. The variation found in our experiment on the first acquisition trial is of smaller order. This difference is understandable upon consideration of the larger degree of restriction which we employed, this restriction effectively increasing the chance of occurrence of the required response within a given time. In Thorndike's investigation, as in ours, there is evidence of a sharp reduction in latent period on the second trial as a consequence of the first. Furthermore, the majority of Thorndike's curves indicate a gradual decline in latent period which occurs throughout the course of acquisition.

A comparison of our data with the results obtained by Hunter (**8**) is difficult because the latter are presented as Vincent curves computed from the number of correct responses in successive tenths of learning. However, if Hunter's percentage measure be taken to represent the strength of response during acquisition, his curves indicate a response strength which increases as acquisition proceeds. Presumably, this is the situation in our experiment if latent period be conceived as an inverse measure of strength. A similar comparison may be made between our data and those of Youtz (**20**), which are presented as changes in frequency of response in successive tenths of learning. This unit also increases in magnitude during acquisition and represents an increase in the strength of response.

The curves of conditioning presented by Skinner (**14**) depict an initial increase in rate of responding. This initial increase is followed by a long period of response at a constant rate which gradually lessens under the influence of a waning drive. In the present study we have been interested only in those changes in response strength which take place in the

presence of a constant drive. Our results indicate the gradual nature of the process of acquisition from the second to the fifteenth trial. Although our curve exhibits its most rapid drop between trial 1 and trial 2, our results do not bear out a generalization to the effect that acquisition is completed in the first trial, but show, on the contrary, that the change in latent period of response from the second to the final trial is about nine-fold in amount. A more precise determination of the initial changes in strength of the lever-pressing response might yield, as Skinner (**18**) suggests, a curve which reveals the gradual nature of the acquisition process.

The curve of experimental extinction presented in this paper exhibits an increase of latent period value with successive trials of non-reinforcement. The measure in terms of frequency of response per tenth of extinction time, employed in the studies of Hunter (**7**) and of Youtz (**20**), declines during extinction, and thus represents a decreasing strength of response. A similar decrease in strength is measured inversely by the latent period used in our experiment. The increasing latent period which we find during extinction is paralleled in Skinner's (**15**) cumulative curves by a declining rate of response.

The present findings on spontaneous recovery may be compared with those of Miller and Stevenson (**9**) who report a very rapid and nearly complete recovery of a similar response after a one-minute interval. Our results indicate an amount of spontaneous recovery which is slight relative to the changes in response which take place during acquisition and extinction. The differences between these two sets of results are probably attributable to differences in experimental procedure. Miller and Stevenson measured intervals immediately following the eighth extinction trial, without the intervening 3-minute extinction criterion which we have used. In addition, Miller and Stevenson measured the length of time taken by the rat to run the alley, rather than latent period of response. Despite these differences, however, the results of both Miller and Stevenson's experiment and our own favor the conclusion that recovery proceeds at a rapid rate during the first few minutes after extinction.

The results which we have described enable us to consider certain important temporal characteristics of operant conditioning. It has often been recognized that a synthesis of operant and respondent conditioning would be desirable from the point of view of economy. It is true that our data provide no new advance on this controversial topic, but it may not be completely out of place to re-emphasize the fact that the two types of response undergo changes in strength in much the same manner and under the influence of variables which have a high degree of formal similarity. To what extent this parallelism is strictly adhered to is a question for further experimentation.

Theoretical

In general terms the phenomena of acquisition, extinction and spontaneous recovery of a response may be said to depend upon (1) the number, n, of paired stimulations by a conditioned stimulus of magnitude S_c and an unconditioned stimulus of magnitude S_u; (2) the number, p, of stimulations by a conditioned stimulus of magnitude S_c; and (3) the temporal course of the effects of these stimuli through time, t. The conditioned response, R, then, may be said to be a function of these variables, and we write

$$R = f(S_u, S_c, t, n, p). \tag{1}$$

The action of the five variables of equation (1) is most clearly visualized if we consider it with reference to an hypothesized internal condition of excitation which we may call e. Magnitude of response, R, is considered to be determined by the level of e present in the organism, and the problem of accounting for acquisition and extinction becomes one of accounting for the amount of e present as a function of the controlling variables of equation (1). By hypothesis, then,

$$e = \phi(S_u, S_c, t, n, p). \tag{2}$$

Figure 5 contains a diagram which may serve as a model to illustrate the hypothesized mode of action of e. It is assumed that e is initially present in small amount. With

continued stimulation by S_c and S_u, e builds up in amount, and the response elicited, R, is stronger as e becomes greater and greater. While it is true that the level of e is probably a function of the magnitude of S_c, it is to be noted that it is

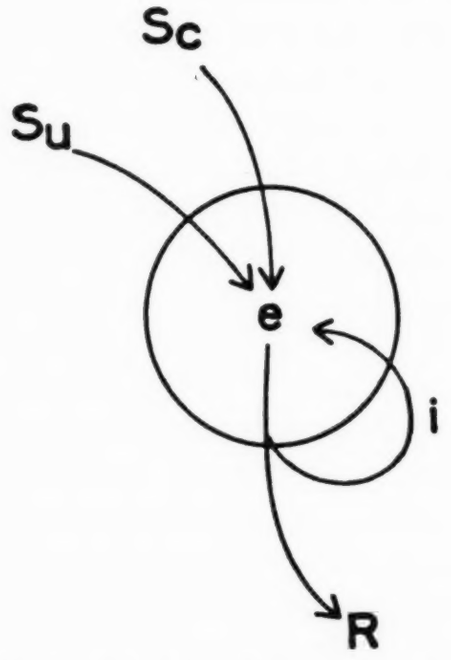

FIG. 5. A model for conditioning. S_c represents the conditioned stimulus; S_u, the unconditioned stimulus; R, the response; e, a condition of excitation; and i, a 'back' inhibitory process.

more importantly a function of S_u. This must be the case, for in the absence of S_u during extinction, R, and hence its determiner e, must decrease in magnitude. Thus, in terms of the model, acquisition is due primarily to the increase in e with repeated presentations of S_u, while extinction is due largely to the decrease in e which occurs in the absence of S_u.

The model as discussed so far does not account for spontaneous recovery. There are a number of possibilities, of varying degrees of complexity, which might give a tentative picture of the process. The one which we have chosen is diagrammed in Fig. 5 by the line indicated as i. It should be emphasized that this mechanism is not in any way to be considered as ultimately 'correct.' In fact we are well aware that it has certain severe limitations, but we also feel that these limitations can be overcome and that the *type* of process

is essentially satisfactory. According to this idea spontaneous recovery is due to the accumulation of inhibition, i, which, on each elicitation of R, deactivates a certain amount of e. This mechanism has the advantage of making extinction a rapid process as compared with acquisition, for in these terms, extinction is not only due to the 'draining off' of e by R, but it also involves the active suppression of e by i. Spontaneous recovery by this account may be considered to be the result of the 'spontaneous' reconversion of i to e at a slow temporal rate which is determined by the amount of i present in the system.

A quantitative description of such a system as we have outlined is complicated by the fact that S_c and S_u do not act continuously through time. The proper consideration of this fact will eventually be necessary for a final theory, and indeed Rashevsky (**11**) has taken account of it in a recent formulation of conditioning. However, the expression derived by Rashevsky is somewhat unmanageable for experimental purposes. For the time being, then, it may be permissible to introduce a certain amount of oversimplification, and this will be particularly true if the hypothesis, as an approximate statement, provides us with implications which may be tested. In what follows we shall consider how e varies with n (the number of trials in acquisition) for fixed S_u and S_c, and with p (the number of trials in extinction) for fixed S_c.

In order to develop a practical hypothesis we make the assumption that the stimulating effects of S_u and S_c, s_u and s_c respectively, are not momentary but are effective throughout the period from one stimulation to another. Specifically, s_u and s_c may be thought of as the average stimulating effects of S_u and S_c throughout a trial. Conceptually, these average effects may act to influence the rate of change of e in a uniform manner throughout the interval between successive stimulations by S_u and S_c for times which are not too long.

With this conceptualization of the role of the conditioned and unconditioned stimuli, we may think of the action of the system in Fig. 5 as following the process described by the following equation, in which, by an assumption discussed

later, i is a function of e:

$$\frac{de}{dt} = k_1 s_u e - k_2 s_c e i + k_3 i. \tag{3}$$

In this equation t is time; s_u and s_c the 'average stimulating effects' of S_u and S_c; and k_1, k_2, and k_3 are constants. This particular equation has certain important properties.[3] (1) If the unconditioned stimulus is discontinued, s_u has a value of zero and the change in e with time will be determined by the terms involving k_2 and k_3. The decrease in e under these circumstances will go on at a rapid rate since $k_2 s_c$ is presumably larger than k_3 and since ei has a much greater effect than the i in the extreme right hand term. This is the process which goes on in extinction. (2) If neither S_u nor S_c is presented, $\frac{de}{dt}$ depends on the term involving k_3 and this expression may be considered to represent the rate of spontaneous recovery. (3) The process of acquisition must be thought of as involving all the terms of equation (3), and it is clear that the accumulation of e depends fundamentally on the presence of S_u.

In order to test this hypothesis on data it is necessary to have an expression in which the response, rather than the hypothetical variables e and i, is treated as a function of time. Let it be assumed that the magnitude of response, R, elicitable on the presentation of S_c is directly proportional to e and to s_c. This latter condition is necessary for Pavlovian conditioning, and it is undoubtedly a requisite for operant conditioning, at least within certain limits above threshold. On this assumption

$$R = k_4 s_c e. \tag{4}$$

In relating R and i we make the assumption that

$$i = k_5 R = k_4 k_5 s_c e. \tag{5}$$

This latter equation assumes that the 'back' inhibitory effect on e is proportional to the magnitude of the response, an as-

[3] Equation (3) may be thought of without reference to an inhibiting factor. This is true because of later treatment in which i is proportional to e. In this case, the second term of (3) [involving e^2] is empirical.

sumption which seems reasonable since we should expect inhibition to be graded by the excitatory effect giving rise to the inhibition.

If we substitute for e and i in equation (3) their proportionalities, as given by equations (4) and (5), we get

$$\frac{dR}{dt} = R(K_1 + K_3 - K_2R), \tag{6}$$

where $K_1 = k_1 s_u$, $K_2 = k_2 k_5 s_c$, and $K_3 = k_3 k_4 k_5 s_c$. This equation involves our fundamental ideas with regard to conditioning, but in order to test its consequences we must remember that conditioning and extinction take place in discrete trials, each of length Δt, and not through continuous time. For this reason it is necessary to obtain an expression which relates R to n or p, the number of trials, rather than to time, t.

The manner in which this may be accomplished is discussed in an appendix. Appendix A deals with acquisition and B, with extinction. It is only necessary to note here that when the proper operations have been carried out we obtain the relationship (A4)

$$\frac{R_{m+n}}{A - R_{m+n}} = KC^n \tag{7}$$

as an expression of the manner in which the response varies with n, the number of trials in acquisition. In this equation R_{m+n} designates the response after n trials as a function of n, and A is the limiting value of R_{m+n} for large values of n. C is a constant which contains length of trial as parameter.

The treatment in Appendix A assumes the presence of a response R_m at the beginning of acquisition. This is necessary, since it may be shown that in some cases the first few responses do not contribute to conditioning, but only to the animal's adjustment to the experimental situation. R_m may be calculated by observing that

$$\frac{R_m}{A - R_m} = K.$$

Extinction, according to the treatment of Appendix B,

equation (B2), is given by the expression

$$\frac{R_p}{R_p - a} = K'c^{p-1}. \tag{8}$$

In this equation R_p is the response, p the number of the trial and a the asymptotic value of R_p for large values of p. K' is a constant defined by the relation $\frac{R_1}{R_1 - a}$, where R_1 is the response on the first trial of extinction.

The description of spontaneous recovery involves none of the complexities involved in acquisition and extinction. It depends only on the temporal processes of i; and for this case equation (3) reduces to $\frac{de}{dt} = k_5 i$, since s_u and s_c have values of zero. On substituting the proportionalities for e and i from equations (4) and (5) and integrating, we obtain, as the expression for spontaneous recovery,

$$\log R/R_0 = K_3 t. \tag{9}$$

This equation states that the logarithm of the response elicitable after an interval involving no stimulation increases with time in a linear manner. R_0, a constant, is the absolute threshold response.

Data and Theory

Equations (7) and (8) indicate the way in which R, the magnitude of response, varies as a function of n and p, the number of trials in acquisition and extinction, respectively. Equation (9) gives the course of R in spontaneous recovery as a function of time. In order to relate these theoretical expectations to the data of the present experiment it is necessary to consider the way in which the latent period, P, is connected with R. Clearly, the two variables are related in an inverse manner, for the long latent period which we find at the beginning of acquisition must be indicative of a small amount of conditioning while the short latent period late in the process must represent a large amount of conditioning,

i.e., a large value of R. For this reason we consider that R is proportional to the reciprocal of the latent period, *i.e.*,

$$R = \frac{m}{P},$$

where m is a constant of proportionality. If we substitute $\frac{m}{P}$ for R in equations (7), (8) and (9) respectively, we arrive at the following expressions in terms of P. For acquisition,

$$\frac{P_\infty}{P - P_\infty} = KC^n. \tag{10}$$

In this equation P_∞ is the asymptotic value approached by P for large values of n. K is defined by the relation $\frac{P_\infty}{P_m - P_\infty}$, where P_m is the latent period at the start of conditioning.

For extinction, equation (8) becomes

$$\frac{P_f}{P_f - P} = K'C^{p-1}. \tag{11}$$

In this expression, P_f represents the asymptotic value of P, and $K' = \frac{P_f}{P_f - P_1}$ where P_1 is the latent period at the beginning of extinction.

Finally, for spontaneous recovery, based on equation (9), we observe that

$$\log P = -K_3 t + \log P_0, \tag{12}$$

an expression in which P_0 is the latent period of the threshold response.

In testing the agreement between data and theory it is well to start with a consideration of spontaneous recovery. This is due to the fact that the function in equation (3) which represents this process is the most uncertain and hence a critical test is required. Equation (12) tells us that log latent period should vary with time allowed for recovery according to a linear relation with negative slope, and reference to Fig. 4 indicates that this is indeed the case for intervals not exceeding six or seven minutes. For longer times the

relation does not hold, and we must accept the fact that (12) is at best a reasonably good approximation. However, the approximation allows us to predict some of the characteristics of conditioning and until greater accuracy is required we may accept the description with a fair degree of confidence.

The agreement between data and theory for acquisition is shown in Fig. 6*A*. The curve drawn through the data repre-

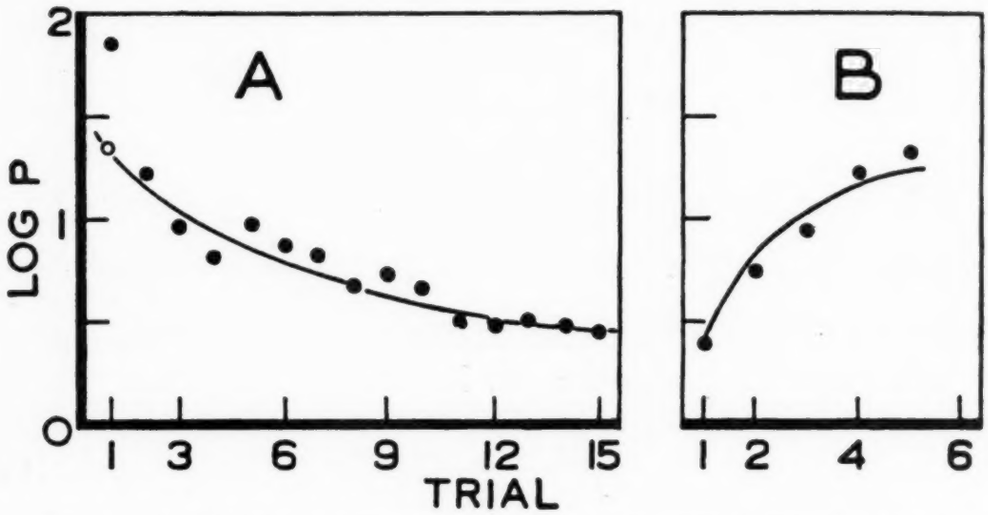

FIG. 6. *A*. The data for acquisition fitted by the curve of equation (10). The values of constants are as follows: $C = 1.3$; $P_\infty = 2.5$; $K = 0.125$; and $P_m = 22.5$. *B*. The data for extinction fitted by equation (11). Constants have the values: $c = 1.2$; $P_f = 30$; and $K' = 1.09$. The points are the averaged values for Groups A and B.

sents equation (10); the filled circles are experimental points and the open circle is the calculated value of P_m. This latter point indicates the 'true' beginning of learning. In these terms, the experimental point for the first trial must be considered to be simply a function of the 'exploratory drive' of the animal before learning has started. Conceptually, the decrement in latent period between trials one and two is due to the increment in effect taking place between the *termination* of trial one and trial two. Thus, it is as if, at the termination of trial one, the animal had received an amount of conditioning which would have been indicated by a latent period, P_m. In the light of this idea it is clear that the data of acquisition are adequately fitted by the theory of equation (10).

Figure 6*B* represents extinction. The line through the

data is constructed from equation (11). The fit is not perfect, but it does represent the nature of the effect in an encouraging way. A number of factors will have to be examined in more adequate detail, but even now we may accept the hypothesis as providing a fairly exact and definitive account of extinction.

Some Further Considerations

The theory of conditioning presented accounts for a number of essential processes. It is clear, however, that a final statement will have to consider some effects which are not dealt with in the present discussion. The problem of retention is one of these. For the present we may consider retention as being a long-time process whose effects are negligible for the periods under discussion. Ultimately it will be necessary to consider the quantitative effects involved, perhaps as parameters of the present hypothesis.

The problem of spacing of trials will no doubt be important in developing greater precision. This is due to the fact that s_u and s_c, 'the average stimulating effects of S_u and S_c,' increase for constant S_u and S_c as the interval between trials decreases. The effects due to variation in these terms may be marked, and further experimental test will be required in order to evaluate their contributions.

It should be re-emphasized that the expression for spontaneous recovery, equation (9), is only a satisfactory approximation. On regarding the model of Fig. 5 we may observe that as i is built up it may serve as a reservoir for e. With continued and rapid stimulation, particularly at the final steady level of acquisition, i may be present in excess and thus may give rise to a later excessive spontaneous recovery. This effect might appear in a subsequent extinction curve as a rapid initial increase in R followed by a decline. In this way we should have an effect which parallels the one obtained by Hovland (**5**) in the extinction of the galvanic skin reflex. The more exact quantitative relations required to account for this have not as yet been worked out.

Finally, we should point out that, according to our ideas, the final level of extinction is an equilibrium between spon-

taneous recovery and a process of decreasing excitation which opposes it. This may be the case, and indeed it seems likely, but it will be worthwhile to examine the characteristics of the final state of extinction in greater detail at some later time.

We wish to express appreciation to Dr. H. K. Hartline of the Johnson Foundation, University of Pennsylvania, and Professor Harold Schlosberg of Brown University for many fruitful suggestions. Professor Gregory K. Hartmann, now of the Physics Department, University of New Hampshire, and Mr. Leonard McFadden of Brown University have contributed greatly to the clarification and final form of the appendix.

Summary

1. This study has been concerned with an analysis of the changes in strength of a conditioned operant response which occur as functions of reinforcement, non-reinforcement, and spontaneous recovery. The apparatus consists of a simple runway, at one end of which is a starting-box and at the other end, a food-box. The measure of response which we have used is termed the latent period. This is defined as the time taken by the animal to leave the starting-box before traversing the runway to food.

2. The latent period for twenty-one male white rats was measured in fifteen reinforced trials, with a constant interval of 75 seconds between successive trials. A curve of acquisition is presented, revealing a response which begins with a log latent period value of 1.85 (corresponding to 71 seconds) and falls off with negative deceleration to reach a log value of 0.45 (2.8 seconds) at the fifteenth trial. The curve exhibits a nine-fold change in latent period from the second to the fifteenth trial.

3. Changes in the latent period of response during extinction were recorded in forty-one rats, the trials being spaced at the same constant 75-second interval as in acquisition. The process of extinction is depicted in a curve showing the change in latent period of response during five unreinforced trials. This curve begins at a log latent period value of about 0.40 (2.6 seconds) and rises with negative acceleration to a log

value of 1.33 (21 seconds). Thus during extinction the magnitude of the latent period increases in the ratio of nine to one.

4. Spontaneous recovery of the response was measured after extinction had proceeded to a criterion of a 3-minute latent period. Recovery was tested in twenty rats, five at each of four recovery intervals of no stimulation. The intervals used were 1 minute, 3 minutes, 6 minutes, and 10 minutes. The progress of spontaneous recovery in these intervals is shown in the form of a graph. Recovery is rapid during the first three minutes, but after 6 minutes the rate decreases rapidly. The recovery after 10 minutes is not complete, as indicated by the fact that the latent period is still of the order of 35 seconds.

5. A theoretical discussion of the results is presented. This considers changes in an internal condition of excitation which may account for a number of the processes involved in conditioning.

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APPENDIX

A. Acquisition

Equation (6) states that

$$\frac{dR}{dt} = (K_1 + K_3 - K_2R)R.$$

Suppose that learning has started before the experiment so that R at the first trial is not zero. Or, alternatively, suppose that the first few trials do not contribute directly to the acquisition, but only to the animal's adjustment to the experimental apparatus. After m trials (positive or negative) acquisition may commence and at the end of these trials the response is R_m. If we disregard the first m trials and take $R = R_m$ when $t = t_m$, the above differential equation has the solution:

$$\frac{R}{A - R} = \frac{R_m}{A - R_m} e^{(K_1+K_3)(t-t_m)},$$

where

$$A = \frac{K_1 + K_3}{K_2}.$$

This is equivalent to

$$R = (A - R) \frac{R_m}{A - R_m} e^{(K_1+K_3)(t-t_m)}$$

or

$$R\left[1 + \frac{R_m}{A - R_m} e^{(K_1+K_3)(t-t_m)}\right] = \frac{AR_m}{A - R_m} e^{(K_1+K_3)(t-t_m)}.$$

The latter equation may be written

$$R = \frac{\frac{AR_m}{A - R_m} e^{(K_1+K_3)(t-t_m)}}{1 + \frac{R_m}{A - R_m} e^{(K_1+K_3)(t-t_m)}}$$

$$= \frac{AR_m e^{(K_1+K_3)(t-t_m)}}{A - R_m + R_m e^{(K_1+K_3)(t-t_m)}}. \qquad \text{(A1)}$$

If a given trial, n, occurs at time t_n, then the process which takes place between that trial and the succeeding trial $n + 1$ will take place within the interval, $t_{n+1} - t_n$. Since the trials are equally spaced throughout the experiment the interval $t_{n+1} - t_n$ is constant and may be termed Δt. By equation (A1) the response at the $(m + n)$th trial, *i.e.*, for $t = t_{m+n}$, is

$$R_{m+n} = \frac{AR_m e^{(K_1+K_3)(t_{m+n}-t_m)}}{A - R_m + R_m e^{(K_1+K_3)(t_{m+n}-t_m)}}; \qquad \text{(A2)}$$

and since the time intervals are of constant length, Δt, we can write $t_{m+n} - t_m = n\Delta t$. Thus, equation (A2) becomes

$$R_{m+n} = \frac{AR_m e^{n(K_1+K_3)\Delta t}}{A - R_m + R_m e^{n(K_1+K_3)\Delta t}}. \qquad \text{(A3)}$$

It is to be observed that $\lim_{n\to\infty} R_{m+n} = A$ in equation (A3), or R_{m+n} approaches A asymptotically. If we write $e^{(K_1+K_3)\Delta t} = C$, equation (A3) becomes

$$\frac{R_{m+n}}{A - R_{m+n}} = KC^n, \qquad \text{(A4)}$$

where

$$K = \frac{R_m}{A - R_m}.$$

B. Extinction

Extinction is described by equation (6) with $K_1 = 0$, *i.e.*,

$$\frac{dR}{dt} = (K_3 - K_2R)R.$$

Taking the response R_1 at the first trial t_1 of extinction we get the solution

$$\frac{R}{a - R} = \frac{R_1}{a - R_1} e^{K_3(t-t_1)},$$

where

$$a = \frac{K_3}{K_2}.$$

This may be resolved by the method used in part *A* of the appendix to

$$R = \frac{aR_1e^{K_3(t-t_1)}}{a - R_1 + R_1e^{K_3(t-t_1)}}.$$

Accordingly,

$$R_p = \frac{aR_1e^{K_3(t_p-t_1)}}{a - R_1 + R_1e^{K_3(t_p-t_1)}}$$

$$= \frac{aR_1e^{(p-1)K_3\Delta t}}{a - R_1 + R_1e^{(p-1)K_3\Delta t}}, \qquad \text{(B1)}$$

since Δt is held constant throughout the experiment. Equation (B1) gives the response as a function of the number of the extinction trial, p, and the magnitude of the response at the beginning of extinction. For certain uses this equation is more conveniently handled if it is expressed

$$K'c^{(p-1)} = \frac{R_p}{R_p - a}, \qquad \text{(B2)}$$

where $K' = \dfrac{R_1}{R_1 - a}$ and $c = e^{K_3\Delta t}$.

HEARING ACUITY OF ANIMALS AS MEASURED BY CONDITIONING METHODS

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In animals—as in man—audiometry involves two main problems—(1) presentation of suitable pure-tone stimuli; (2) a reliable indication of reception.

1. *Pure-tone Stimuli.*—The importance of using pure tones to stimulate the cochlea is obvious. To generate such tones some workers have used a standard clinical audiometer. In its usual form this instrument has two important shortcomings when applied to animals; first, the inadequate upper frequency limit of 8192 cycles; second, the difficulty of holding the ear piece with a uniform pressure against the ear. This latter is particularly difficult in naturally restless animals. To overcome these deficiencies some workers have installed audio-oscillators of greater frequency and intensity ranges, and adopted conventional loud-speakers to convert these frequencies into sound. This procedure brings up the very complex physical problem of maintaining a known sound field about the head of an animal subject. Absolute calibration of such a sound field would be a formidable task for the ordinary animal laboratory. Fortunately, a good substitute is available and has been used by several workers (*cf.* Wendt, **12**); one proceeds first to determine the instrumental settings for a series of hearing thresholds in young human subjects, then converts these instrumental readings into real sound units by referring to the curves published by such workers as Sivian and White (**10**).

The manner in which the tone stimuli are presented is important. Properly, such tests must be carried out in silence rooms, where the noise level is very low, and even a faint sound assumes large stimulation-value. At the same time—whether due entirely to the effects of the weak stimuli em-

ployed, or in part to the unnatural surroundings—the general excitability of the subject is heightened (see below). Some adventitious sounds which might under ordinary circumstances pass unnoticed can therefore elicit responses. A common source of trouble is the click which occurs whenever the sound is turned on by quickly breaking a short-circuit across the speaker leads. Wendt (**12**) has called attention to a different click—this one, intra-aural in origin—which occurs whenever the tone is turned on rapidly, by whatever means.

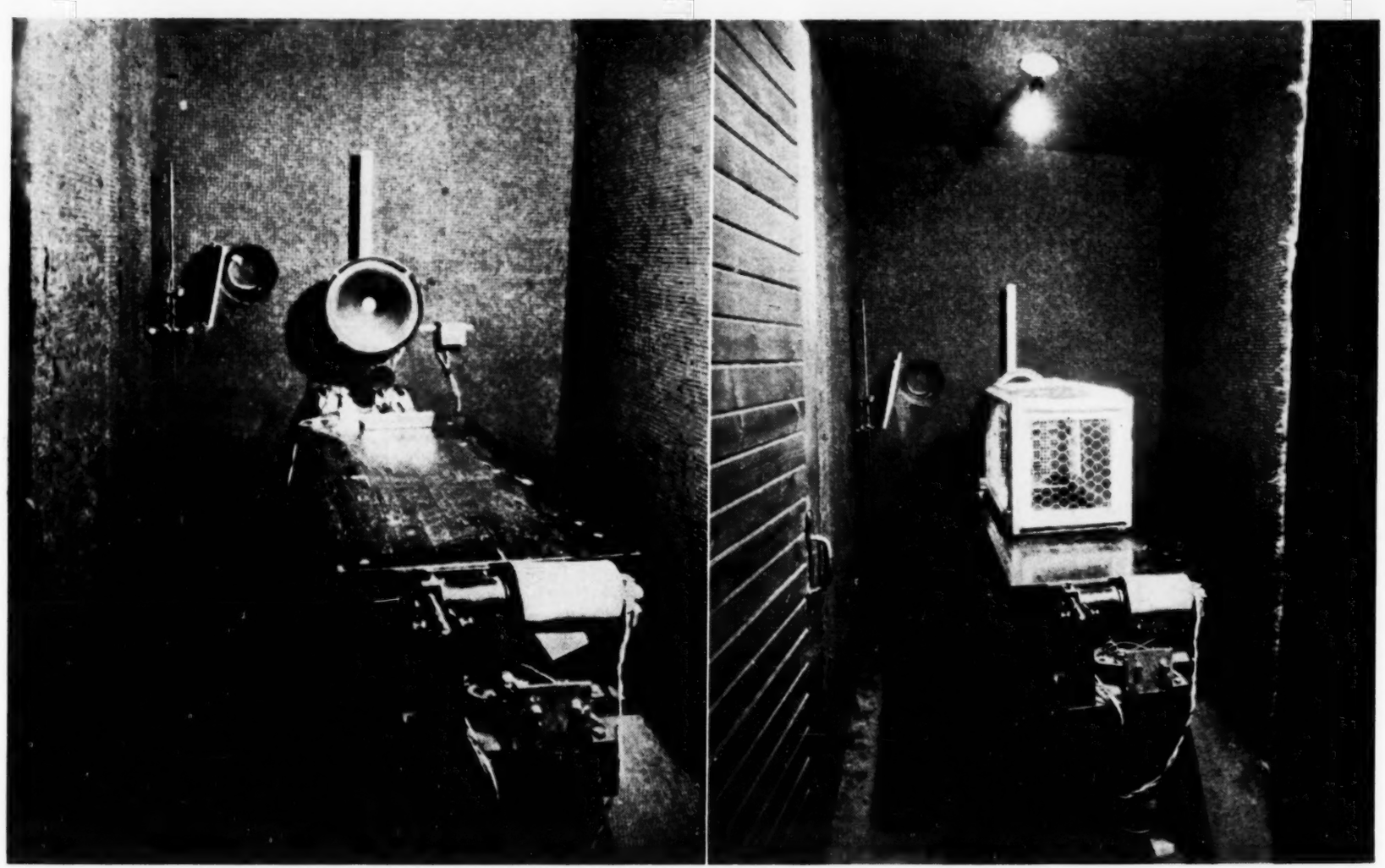
2. *Conditioned Responses as Indicators of Reception.*—It is noteworthy that among workers who have tested hearing by a training technique the original Pavlov salivary method has been almost wholly abandoned.[1] One reason, of course, is that saliva cannot be readily measured in animals as small as the guinea pig, monkey, or cat. Every worker has devised his own version of conditioning, and some of the modifications are far removed indeed from the original Pavlovian procedure. Wever (**13**) in the cat, Upton (**11**) and Horton (**9**) in the guinea-pig, conditioned the respiratory movements to a tone-shock combination. In these researches the subjects were securely fastened in a cradle-like holder. While this procedure served the useful purpose of keeping the animal's head fixed in the sound field, it apparently did not evoke the strong natural reaction to restraint which Pavlov calls the 'freedom reflex'—and which can play havoc with the progress of conditioning. Culler and his associates (**2**) employed, for the most part, a motor reaction (flexion-reflex to nocuous stimulus, as used extensively by the Liddell school). They have introduced one interesting innovation—occasionally the shock (reinforcement) is replaced by the sound of a buzzer. Elder (**7**) has devised for the chimpanzee a complex motor-alimentary method in which the animal is trained to

[1] Attempts to apply the salivary technique to audiometric tests in dogs were first made by G. F. Sutherland in this laboratory. The data obtained, not hitherto published, indicated a frequency-intensity curve similar to that of man. In the course of these, and later studies carried out by one of the present writers, it became apparent that the salivary method was in some respects unsuitable when the dog was confronted with stimuli of threshold value. In some dogs salivation ceased entirely, and could not for some time thereafter be elicited by any strength of stimulus; in others it became continuous and profuse.

respond first to a 'ready' signal by waiting expectantly, then, at the onset of a tone-stimulus, to press a key which provides food. Wendt (**12**) used a similar response-method in monkeys.

The above-described modifications of the Pavlov method were justified to a large extent because, as Elder (**7**) remarks, selection of apparatus and methods in animal experiments should be determined to a great extent by the type of subject used. Yet it is worth while emphasizing that the inherent value of the Pavlov method lies not so much in the collection of saliva as in the rigorous conditions under which the experiments are performed. Among its outstanding requirements are: (1) complete isolation of subject from observer; (2) observation of proper time intervals between successive stimuli so as to allow wearing-off of positive and negative induction; (3) use of more than one form of sensory stimulation; (4) simple and direct relationship between the stimulus and the reinforcement. If these features are important in studying the effects of ordinary stimuli, they assume a far greater role when one seeks to determine presence or absence of response to stimuli of liminal strength.

For testing hearing of cats, Dworkin, Sutherland and Seymour (**4**) have described a method which combines most of the above-mentioned features with a suitable index of reception—namely, lifting the lid of a food container. In the first experiments with this method, cats were subjected to a preliminary training in a small box, then to a finer training in a sound-proof room. Now the entire training is done in an improved sound-proof room, and, with further refinement of the audiometric apparatus, the method has also been applied to the testing of the dog's hearing. While the new procedure has been mentioned in a previous account of hearing in normal and abnormal animals (Davis, Dworkin, Lurie and Katzman, **3**) it has hitherto not been published in detail. The object of this communication is to describe the testing procedure in use at present—with reference both to the production of the pure-tone stimuli and the suitability of the motor-alimentary response. The frequency-intensity curves of cat and dog, compared with that of man, are also described.



A *B*

FIG. 1. The animals' sound-proof compartment in the conditioning laboratory. The observation table is placed directly in front of the post which carries the two sound transmitters. At the far end of this table is shown the food-lid, which the animal is trained to lift up to obtain its food. A dog would be placed directly upon the table, and held in place by a harness suspended from a cross-bar (not shown). A cat would be enclosed in a cage mounted on the table, as shown in *B*. The camera mirror is placed behind the speakers, out of the sound field.

1. *General Equipment.*—The plan of the conditioning laboratory followed that specified by Pavlov. Separate chambers were provided for the animal and for the observer. The animal's chamber was adequately sound-proof.[2] The internal dimensions of the animal's compartment were 7¼ feet (height) × 7¼ feet (length) × 4¼ feet (width).

Within this compartment a cat was enclosed in a wire cage, made of one inch mesh. The dimensions of this cage were 24 inches (length) × 12 inches (width) × 16 inches (height). The cage was large enough to permit a cat to turn about, but small enough to prevent free wandering. This cage was placed upon a table-top, the latter in turn mounted upon a massive cast-iron base. The dog subjects were placed directly upon the table, and held in position by a light harness.

Beneath the front end of the table was the food-carrier which consisted of a revolving tray supporting eleven food cups. This device is shown in Fig. 3. Access to the cups was provided by a hole cut in the edge of the table. The hole was covered by a hinged lid, which the animal must raise to obtain the food.

Two sound transmitters, comprising high- and low-frequency speakers, were mounted on a steel rod, set in a slab of concrete. The height of each speaker was adjustable and the usual practice was to place the centre of the speaker at the level of the subject's head, and 15 inches distant. The concrete post also supported various lights, bells, and buzzers. The interior of the animal's compartment is shown in Fig. 1.

Part of the observer's chamber is shown in Fig. 2. Through a camera obscura set in the thick stone partition, the subjects could be viewed at all times. The specific responses (opening and closing of the lid), as well as the occurrence of the stimuli, were recorded on a kymograph. The audiometer and other apparatus used for measuring the tone-stimuli were mounted on two relay racks, entirely separate from the electrical apparatus used for producing other signals, recording etc.

2. *Production and Measurement of the Pure-tone Stimuli.*—Our animals were tested at 8 or 9 of the following frequencies: 100 cycles per second, 200, 400, 1000, 2000, 3000, 5000, 8000, 10,000, 14,000, 16,000. These frequencies were generated by means of a low-frequency battery-operated oscillator (General Radio Type 377B). To convert them into sound, we used a permanent-magnet dynamic transmitter for the low, and a high-frequency unit activated by a 6 volt field, for the high pitches.

The following apparatus was used to control the intensity: a power level meter, a calibrated audio-frequency amplifier and an attenuation network (General Radio Type 249T). These instruments were so arranged that any one could be plugged in at any part of the circuit.

The intensities of our sound fields were measured by several different and for the most part indirect methods. First, hearing thresholds were determined in a group of 30 young men and women with excellent hearing, and the instrumental settings at each point (decibels below a constant output of 6 milliwatts) converted into actual sound

[2] The walls were of brick, varying in thickness from 18 to 28 inches. The inside lining was of composition board and 1-inch absorbing felt. The heavy construction was good enough to keep out the loudest air-borne sounds met in the immediate surroundings. However since the laboratory was otherwise in immediate contact with the floor and ceiling of a large building, some of the building-vibrations were able to pass through. In particular, a neighboring elevator and loud footsteps overhead could be perceived. These extraneous stimuli were recorded, in relation to observed changes in the subjects' behavior.

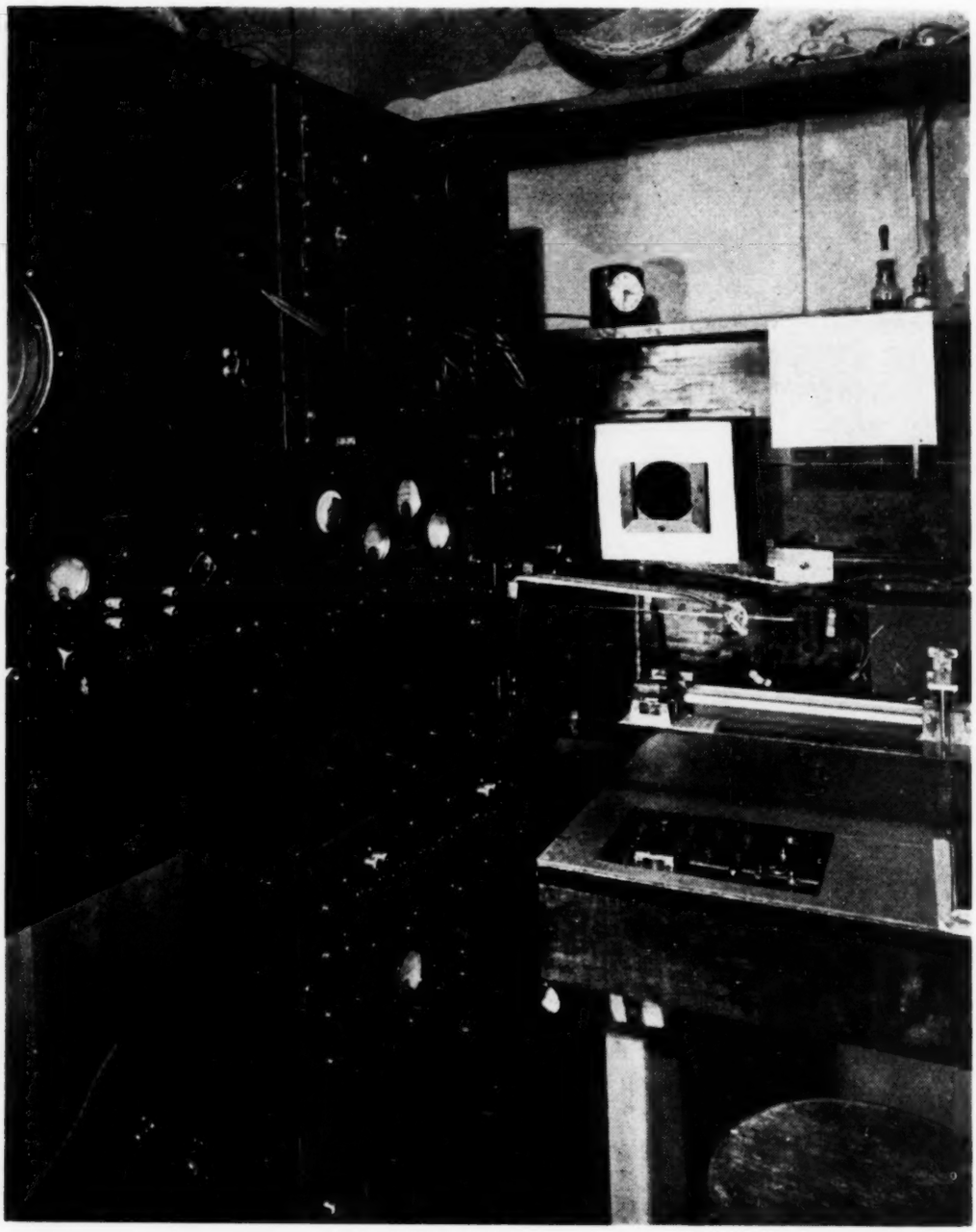


FIG. 2. The observer's chamber in the conditioning laboratory. On the table at the right are to be seen the kymograph and the general control panel, which contains the switches for the rotary feeder as well as all signals except pure tones. The audiometer and auxiliary apparatus are shown at the left. The camera is outlined in white.

units by using the absolute data of the Bell Telephone workers referred to previously. The differences in amount of attenuation needed for the animal thresholds were added to or subtracted from these settings (db. attenuation). The validity of the latter part of the procedure would depend on the following factors: constancy of power output, constancy of attenuation, the known ratio of power input to sound output in the speakers. These factors were controlled in a number of ways: (1) by measuring the current entering the speakers; (2) by picking up the sounds themselves with a carbon-type microphone and calibrated amplifier; (3) by placing a Rayleigh disc in the sound

field and noting the actual sound pressures. It should be stated that the first method was suitable for all the intensities; the latter two only for the greater intensities. The use of the Rayleigh disc was further limited to the 2 frequencies of 1000 and 3000 cycles.

Considerable difficulty was met in our attempts to attenuate the frequencies above 3000 cycles. In the case of 5000 cycles, for example, even full attenuation (110 db.) of the original current still induced enough sound to elicit responses in the

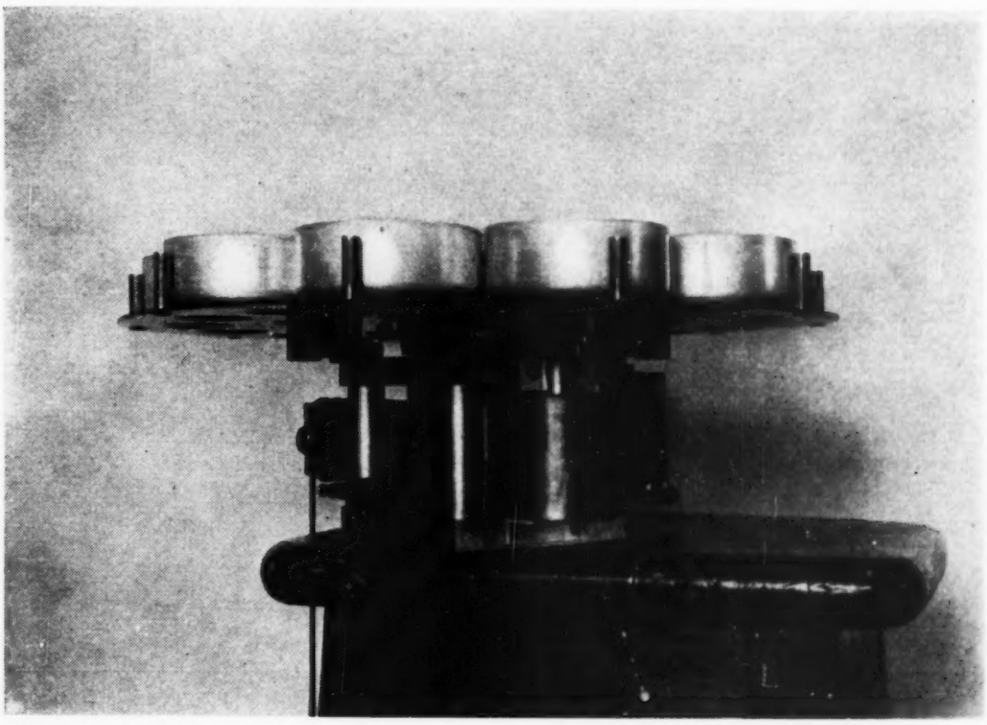


FIG. 3. The rotary feeder. The food cups are set on a turntable. The latter is turned by gravity when a holding magnet is de-energized, and stopped at each feeding-(positive) stimulus automatically by means of a timing relay.

cats. These responses occurred not during the early tests of thresholds, but only after the subjects had been exposed repeatedly to sounds of near-threshold or threshold strength. To eliminate these faint high-pitched tones, elaborate means were taken to insulate, shield and ground the audiometer and its connections. As a further step special transformers were built to match line and speaker impedances at the various frequencies.

Three different procedures were used to ensure a smooth onset and cessation of the pure tones, as well as to prevent simultaneous clicks and other adventitious sound-stimuli. In one, the output potentiometer of the oscillator was driven mechanically at a uniform rate by attaching it to an automatic telephone dial. This driving device is shown in Fig. 4. A second procedure was to drive the potentiometer in the feed-back circuit by another telephone dial. In the third method, the filament of an intermediate amplifier was lit and extinguished by use of a simple key. The near-threshold, threshold, and sub-threshold stimuli were presented repeatedly by all three methods.

3. *The Training Procedure.*—The raising of the lid (Dworkin, Sutherland and Seymour, **4**, Dworkin, **5**, **6**) is not a true reflex; nevertheless with sufficient training it becomes very firmly established. Indeed the writers, and separately Winslow, Kantor

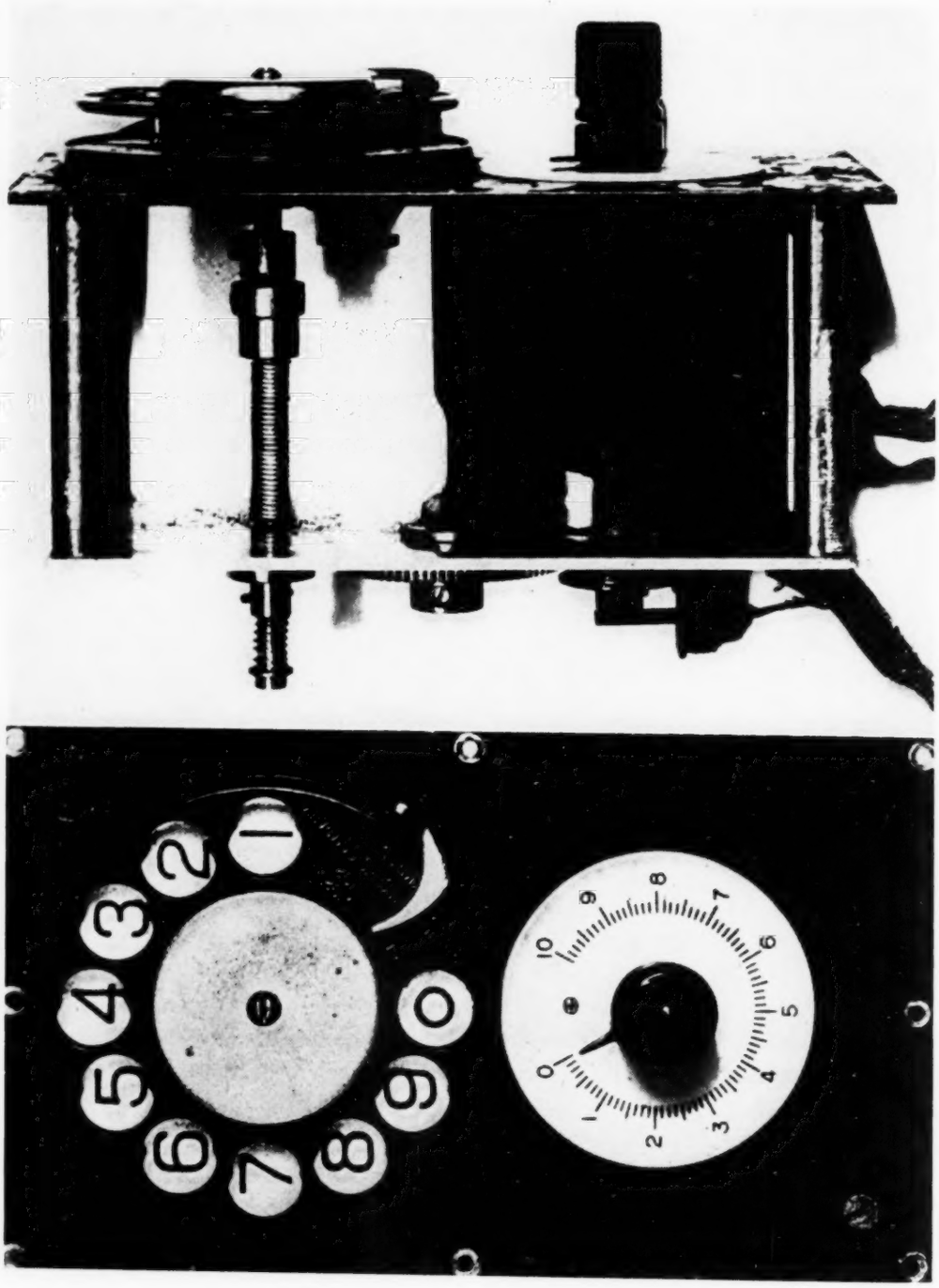


FIG. 4. The driving mechanism which is used to turn the tones on and off at a uniform and rather slow speed.

and Warden (14) have used this response to study many aspects of conditioning in general.

In the cat, from the first training, the time needed to measure hearing acuity varies from 3 to 6 months. The dog is apt to be somewhat refractory—especially during the early training, and may require a longer time. All of the training is done in the sound-proof room. For subjects young adult animals are preferred.

At the start, a cat receives a milk diet only for 48 hours, and is then taken to the cage within the sound-proof room. The observer remains in the same room as the animal during the first 3 to 4 training sessions, each session being of 40 to 60 minutes duration.

The hungry animal is allowed, immediately, to pick up several small pieces of meat dropped on the table just in front of the food lid. Later the observer holds the lid open and trains the cat to pick the small meat portions out of the food cups. In the next stage the cat learns to pry open the lid and hold it up with its head while it proceeds to lift the meat out. At the beginning of the 2nd training period most cats have learned to work the lid continually, and, to prevent extinction of this early training, care must be taken to provide a feeding every 60 seconds. During the 3rd training period the meat pieces can be delivered by moving the rotary feeder by remote control. The sound caused by the movement of this feeding device itself provides a stimulus for raising of the lid. When this response is established, the observer may leave the animal alone in the sound-proof chamber and take up his post in the control chamber.

At the third or fourth session a quiet bell or buzzer is sounded, at 1 to 2 minute intervals, and the feeder is moved from the control room some 2–5 seconds later. The number of 'responses' at this stage far exceeds the number of stimuli, and during this early training it is difficult to find any relationship between the responses and the signals. This furious activity subsides gradually, and definite evidence of conditioning appears at the 20th to 30th trial. It is advisable to let the excessive responses disappear spontaneously, rather than to punish the animal for 'wrong responses.' In our experience with the cat, physical punishment results in permanent inhibition, which, of course, renders the animal useless for further work. Complete subsidence of excessive activity occurs, as a rule, in 14 to 20 days in the cat. In the dog excessive responses are not a very prominent feature, and disappear during the early training.

When the early excessive activity has disappeared and the animal responds promptly to a bell or buzzer signal, training is begun to a light-stimulus. The purpose of the latter form of stimulation is to test the general irritability of a subject that may cease to respond to an auditory stimulus. It is only after the animal responds readily to bell or buzzer and a light, that pure-tone stimuli are introduced. Any frequency between 400 and 5000 cycles may serve as a start, at a loudness of about 40 decibels above threshold. A typical order of sequence of the stimuli at this time would be as follows:

Time	Stimulus
2:33	Weak bell
2:36	White light
2:38	Tone, 2000 cycles
2:42	Tone, 2000 cycles
2:44	Tone, 2000 cycles
2:47	Tone, 2000 cycles
2:49	White light
2:52	Tone, 2000 cycles
2:54	Tone, 2000 cycles

Conditioning to pure-tone stimuli at this stage of the training proceeds smoothly and is characterized in the cat, but not in the dog, by wide generalization. This means that once a cat responds promptly to a tone of 2000 cycles it will thereafter respond almost as promptly to each of the other frequencies used. In the dog additional reinforcement may still be needed to establish responses to the higher and lower pitches.

From this point, exploration of the hearing thresholds is a matter of reducing, in gradual stages, the intensity of each of the frequencies used. A typical experiment in which this was done is as follows:

Time	Stimulus	Latent Period of Conditioned Response, Seconds	Latent Period of Unconditioned Response,[3] Seconds
9:00	White Light	5	1
9:03	3000 + 30 db.	2	1
9:06	3000 + 20 db.	2	1
9:07	3000 + 10 db.	5	2
9:09	3000 − 10 db.	—	Not fed
9:10	3000 + 15 db.	3	2
9:12	3000 + 5 db.	—	3
9:15	3000 − 5 db.	5–7	1
9:18	3000 + 20 db.	1–2	1

[3] By this is meant the response to the movement of the rotary feeder, which is not only heard but perceived through tactile stimulation.

As regards proper time intervals between successive trials, the following periods have been found to give optimum results: 1, for the first training, with the observer in the same room as the animal, 15 to 60 seconds; 2, in the first training with the observer in his own compartment, 30 to 75 seconds; 3, when the first tone-stimuli were tried, 1 to 2 minutes; 4, in the final threshold determinations, 2 to 5 minutes. However, in practice the optimum time intervals proved to be different for different individuals. Thus some cats tended, consistently, to pry the lid open spontaneously after a wait of 1½ minutes; others, after an interval of 3 minutes. Further, some animals tended, just as consistently, to be inhibited if compelled to wait more than 1½ minutes after a stimulus of doubtful intensity (which did not elicit a definite response and was therefore not re-inforced); while most of the other subjects displayed excessive activity.

Preliminary or 'warning' signals were tried in some of the early experiments, but did not accelerate the training nor reduce the amount of excessive activity. They were therefore abandoned in all subsequent tests.

For each frequency it required, at first, several days to establish a definite threshold. Later one to two days were sufficient. Since the different frequencies were tested in turn, this part of the training took a usual time of between 6 and 12 weeks.

A constant finding was that thresholds established in the early tests were higher by from 5 to 25 decibels than those obtained after repeated trials. The lowering of the thresholds

was apt to occur suddenly rather than gradually, at about the time that a characteristic state of neuro-muscular hypertension was evident. On direct observation, the cats were seen to hold their limbs rigidly, and to make sudden sharp movements of the head or body usually in a forward direction. When an audible signal occurred, the animals suddenly leaped toward the food container. When the tone-stimuli were of threshold strength, definite disturbances of the hitherto smooth behavior were noted in many subjects. These disturbances varied from occasional false responses to great hyperactivity. Rarely, a complete, though temporary inhibition of the lid-lifting response supervened. An account of these reactions is being published elsewhere. One result of the exaggerated tension was that the cats were certain to respond to every stimulus present, regardless of the source. While those stimuli which arose outside of the laboratory were kept out by the sound-proof walls, there was no way of preventing stimulation by the sounds of the animals' movements whether muscular contractions or rubbing of the fur, or impact of the feet and body upon the floor and walls of the enclosure. It was interesting to find that our human subjects had much less difficulty in determining the presence or absence of the pure tones. It would seem that the latter learned early to discriminate between the proper, and such adventitious sounds, as may arise; but the sensitive and hungry cats seldom developed the requisite inhibition.

In the cat, the attaining of actual threshold was indicated by one of three reactions: (1) lengthening of the latent period and failure to open the lid; (2) sudden and continued inhibition; (3) few, or frequent false or 'interval' responses. The latter reaction has been seen in the monkey, also during test of hearing acuity, by Wendt (**12**) and in the dog during similar experiments by Culler and collaborators (**2**).

In Fig. 5 are shown typical responses, by 2 different cats, to tone stimuli that were attenuated in successive trials from a loud level to a point where they could no longer be perceived.

When, as the result of progressive attenuation of the sound, the response failed, the exhibition of a light-stimulus

was of value in showing the state of general reactivity. For most cats, light is ordinarily a weak stimulus, and usually evokes a response after a latent period that is considerably longer than that which follows a loud sound or tactile stimula-

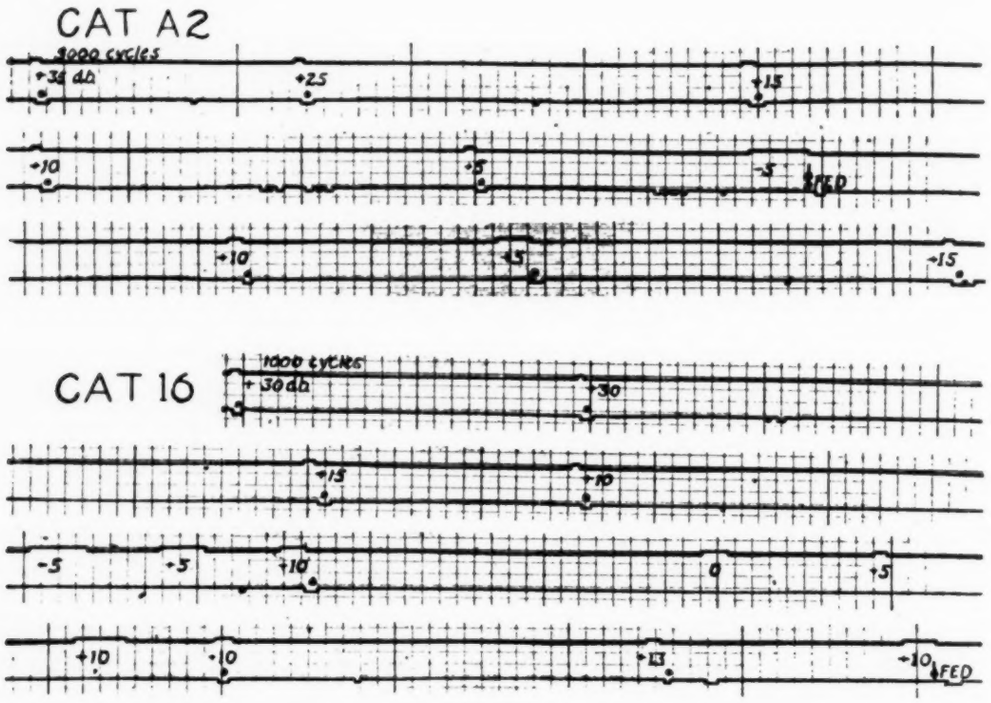


FIG. 5. Records, from two different cats, of behavior in response to a series of pure-tone stimuli. These stimuli are quite loud at the beginning of each of the records, and then progressively attenuated until they are no longer perceived.

In each record, the upper line represents the occurrence of the stimuli, the lower line, the responses. Time, between any two vertical lines, is 6 seconds. The actual loudness, in decibels above the average threshold for the particular frequency, is stated for each tone-stimulus. The black dots mark the presentation of the food.

In the case of the first cat subject, as the stimulus becomes weaker, the latent period of the response becomes longer, until it fails entirely. A subsequent louder stimulus elicits a good response. Note also the occurrence of interval or false responses between successive presentations of stimuli of doubtful strength.

In the second cat, the lengthening of the latent period is again seen as the tone becomes more difficult to hear. However there is very little interval activity. The actual threshold in this instance is about ten db. above the average for the 1000 frequency. Note the inhibition in the last trial, when a stimulus that has previously been strong enough to evoke three responses is ineffective.

tion. But during the threshold tests even a weak light assumed powerful stimulating value, for now the latent period was reduced to 1 or 2 seconds. The changed significance of the light stimulus is shown in the following two experimental protocols:

THE RESPONSE OF CAT 37 TO STIMULI OF DIFFERENT INTENSITIES

Time	Stimulus	Latent Period of Conditioned Response, Seconds	Latent Period of Unconditioned Response, Seconds (see previous footnote)
June 19, 1937			
2:29	White Light	8	1–2
2:31	Bell	2	1–2
2:35	3000 + 50 db.	2	1–2
2:37	3000 + 40 db.	3	1
2:40	White Light	4	1
2:41½	Buzzer	1	1–2
2:45	3000 + 30 db.	2	2
2:47	Bell	3	1
2:50	White Light	5	5
Sept. 11, 1938			
1:14	2000 + 30	2	4
1:15½	2000 + 20	3	2
1:18	2000 + 20	2	3
1:19½	2000 + 10	4	1
1:22½	2000 − 5	—	Not fed
1:24	2000 + 5	14	3
1:28	White Light	2	1
1:30	2000 + 10	7	3; hesitated
1:33	White Light	1	5

In animals in which false responses became so frequent as to make it impossible to correlate any of the responses with the known sound stimuli, the day's experiments were discontinued. When testing was resumed on the next day, the first 3 or 4 trials proceeded well, but the subsequent tests were disturbed by more and more interval activity. Sometimes these excessive responses could be quelled simply by introduction of a strong stimulus, as noted by Culler and collaborators (**2**). In some subjects a rest of from several days to 3 weeks was necessary. Occasionally the amount of the interval activity could be controlled by feeding the animal just before the beginning of the test period.

The question of reinforcement of the weak-tone stimuli was at first a difficult one. In the more recent experiments the practice has been to present food when the tone, regardless of its intensity, was followed by a definite response. Further, when the intensity of the tone stimulus was 10 db.

below the average threshold and the animal did not respond, food was presented at two successive trials after twenty seconds' presentation of the tone, but not thereafter.

Of seven dogs which served as subjects in some of these tests only two lasted long enough for establishing of audiograms; four developed serious behavioral disturbances. Besides two dogs, nine cats were able to go through the entire training procedure without apparent behavioral disturbances. In these 11 animals a complete set of frequency-intensity relationships was established. In 24 other cats definite thresholds were obtained for several, but not all, of the frequencies mentioned. The average figures, as shown in

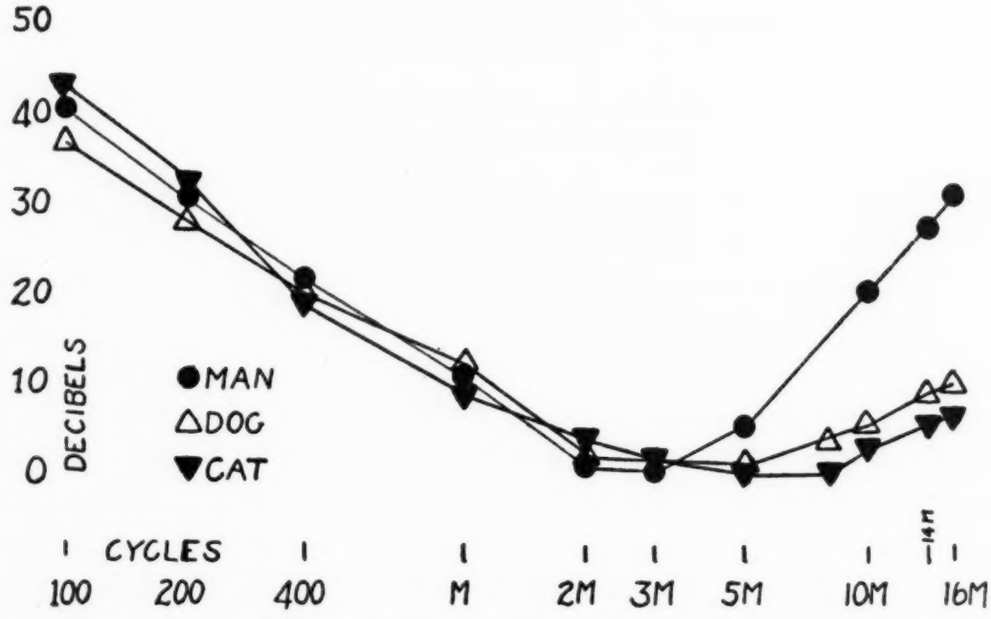


FIG. 6. The sensitivity curves of dog and cat, compared with that of human subjects. Ordinates represent intensity in decibels; the reference point—o db.—is that of the most sensitive threshold in man, that at the frequency of 3000. Abscissae represent frequencies in cycles per second.

Fig. 6 represent a minimum of 50 determinations in cats, and 6 determinations in dogs, at each frequency.

In a few cats it proved, despite the many precautions taken, impossible to arrive at any definite thresholds for frequencies between 1000 and 14,000 cycles. Without showing any special disturbance of the general behavior, these subjects simply responded to tones that were attenuated to a point far below the average thresholds. These responses

occurred only when the (attenuated) tone-signals were turned on, and must therefore be attributed to some unknown accompanying sound.

Figure 6 shows the average hearing thresholds of dog and cat, as compared to those of man. It will be noted that at the lower pitches the curves are quite parallel; but at the upper pitches the animals' hearing is considerably more acute. There is a further difference between human and animal hearing in that the most sensitive point for the former is at the frequencies of 2000 to 3000 cycles, while for the latter subject it extends from 3000 to 8000 cycles. At 10,000 cycles the animals hear better by about 15 db., while at the upper limits of 14,000 and 16,000 the animals' superiority amounts to between 20 to 25 decibels. In the main these results agree with the findings of Wendt (**12**) on monkeys and of Elder (**7**, **8**) on chimpanzees. However, both of the latter workers report a marked loss of sensitivity at the 4096 frequency, a point not borne out by the present research. Elder also found a difference in intensity level of about 25 db. between the human and chimpanzee curves at each frequency except one, but believes that his human subjects with opportunities for practice equalling those of the chimpanzee would show thresholds similar to those of the latter.

Whether the superior hearing of the animals at the higher frequencies is real is an unsettled question. Indeed the whole problem of the upper frequency limit of hearing in animals calls for further clarification on the instrumental side. Elder (**8**) reported that his chimpanzees could hear frequencies of 26,000 to 33,000 cycles, a range of audibility far beyond that of his human subjects (though not of young children). Andreyev (**1**) found an upper frequency limit in the dog of between 36,000 and 38,000 cycles. One of the present writers (S.D.) has compared perception of high frequencies by cats and human subjects when different types of loud speakers were used. Invariably, as the frequencies were increased, human hearing failed before the animals'. While the physiological response was definite, no final conclusion can be drawn from these tests without knowing the nature of

the sound stimulus that came out of the transmitters at these frequencies.

As regards constancy of our thresholds, day to day discrepancies of plus or minus 10 decibels were common, and at times our cats' thresholds varied by as much as 15 decibels. Considering the fact that we left our sensitive cat subjects quite unrestrained with respect to head and body movements, these discrepancies are to be expected. It happened that with persistent training our cats learned not merely to take up a position over the food-lid, but to remain just there for rather long periods and even to explore the sound field for themselves by rapidly moving their heads. Animals which moved about excessively during the early training periods were discarded.

As regards the comparative suitability of dog and cat as subjects, we would say that for mere determination of the presence or absence of sound perception, the cats were much better. In the cat the inhibitory functions were weak, and seldom dominated behavior; this species also was curiously indifferent to most external stimuli, and, once trained to respond to one frequency responded quite readily to others with little further training. Failure, on the experimenter's part, either deliberate or accidental, to reinforce some of the stimuli of doubtful loudness might produce serious behavioral disturbance in the dog, but left the cat quite unaffected. It should be added that, where one is concerned with problems of tone-discrimination, the dog would be preferable, because in this subject inhibition can be more readily established and better retained (*cf.* Dworkin, 5).

Summary

With the use of the motor-alimentary conditioning method, dogs and cats were trained to respond to pure tones. Ultimately thresholds were determined for 8 or 9 different frequencies between 100 cycles and 16,000 cycles, inclusive. The minimum audible fields were also compared with those of a large group of young human adult subjects. The sensitivity curves of both animal species were almost identical.

As compared to man, there were two main differences. In the animals, the most sensitive point was between the frequencies of 5000 and 8000 cycles, as against 2000 to 3000 cycles in man. Secondly, the animals' hearing was considerably more acute at frequencies above 5000; thus, at 14,000 to 16,000 cycles it was superior by about 25 decibels. Unquestionably the upper frequency limit of hearing is higher in animals than in man. The problem is, however, complicated by lack of data on the performance of sound-transmitters at high frequencies.

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AN EXPERIMENTAL INVESTIGATION OF PAVLOV'S CORTICAL IRRADIATION HYPOTHESIS [1]

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AND
DANIEL G. DITTMER
University of Wisconsin

Pavlov and his students first reported the initial generalization of a tactile conditioned response (**11**). Generalization was evidenced by a progressively decreasing magnitude of response as the points of stimulation became increasingly remote from the point conditioned. The decrease in magnitude of response was referred to as a *generalization gradient.* To explain this gradient, Pavlov postulated a wave-like spread of some excitatory process across the cerebral cortex. This spread across the cortex was called *irradiation*, while the opposite process, in which the excitation receded and became gradually limited to the cortical representation of the primary conditioned stimulus, was called *concentration.* The phase of concentration was reported to follow irradiation.

The initial objection to Pavlov's theory of cortical irradiation was voiced by Denny-Brown (**3**), who stated that the assumption was not necessary if one assumes that a response is conditioned only to the general properties of the substitute stimulus until another stimulus is negatively conditioned to eliminate these general properties.

In a critical review of several experiments reported by Pavlov (**11**, Lecture IX), Loucks (**9**) pointed out that the experiments which Pavlov cited failed to demonstrate irradiation and also failed to demonstrate the existence of a generalization gradient. Commenting on an experiment by Anrep

[1] This experiment was carried out at the University of Wisconsin during the summer of 1939 and was supported in part by a grant from the graduate research fund for 1939–40. The writers wish to thank Dr. Harry F. Harlow for assistance in the formulation and preparation of this paper.

(11, pp. 162–164), Loucks admitted that it showed a gradient, but he questioned the validity of Anrep's technique of tactile stimulation. Moreover, he doubted the completeness with which Anrep reported his data.

In an attempt to clarify some of the points in question, Bass and Hull (2) studied the generalization of a tactile conditioned response in man. The summarized data of this experiment gave a clear-cut generalization gradient. Loucks (10), however, pointed out that no irradiation had been demonstrated in this experiment and distinguished sharply between cortical irradiation, the progression of a wave of excitation across the cortex, and the existence of a comparatively static generalization gradient. In the present paper Loucks' usage will be followed in referring to the observable gradient as *generalization*, and in referring to the hypothesized brain-state as *irradiation*.

Hovland (5, 6, 7, 8), in a series of well executed experiments, studied the nature of generalization gradients based on varied frequencies and intensities of auditory stimuli, and on varyingly located vibro-tactile stimuli. His summarized results also demonstrated the existence of generalization gradients. Like Bass and Hull, Hovland made no attempt to prove or disprove the existence of cortical irradiation. These authors stated that they did not wish to commit themselves to any theory of generalization.

No studies attempting an experimental test of the existence of cortical irradiation have come to the attention of the present writers.

Problem

The problem of the present study was to compare the gradients resulting from tactile conditioned responses generalized over two bodily areas having quantitatively different cortical representation. If the theory of cortical irradiation holds, and if generalization gradients are obtained from two bodily regions with different extents of cortical representation, then the gradient from the region with the greater representation will be the steeper of the two. This will be the case because the cortical representatives of the points on the skin

are farther apart on the larger cortical region, and thus the irradiating excitation of this cortical area will suffer a greater decrement between points than will occur between corresponding points on the smaller cortical area.

The regions selected for the present study were the back, from shoulder to waist, and the dorsum of the hand, from the tip of the index finger to the wrist. According to Penfield and Boldrey (**12**), the cortical representation of the hand is considerably greater than that of the trunk. These authors examined the somatic sensory and motor representation of the cortex by the technique of direct electrical stimulation of conscious subjects. In answer to questions submitted by the present writers, Dr. Penfield stated that there might be a difference between the extent of cortical representation of the dorsum and the palm of the hand, but that he and Dr. Boldrey had never attempted to distinguish between the two.

Pavlov assumed that the topography of the skin areas was mapped out with reasonable accuracy on the cortex. In view of the data available on tactile generalization gradients, it is evident that this relationship must exist if generalization is to be explained in terms of cortical irradiation. Accordingly this assumption is accepted for the sake of Pavlov's argument, although it is probably incorrect (*cf.* the grotesque appearance of the homunculus drawn by Penfield and Boldrey to illustrate the size and sequence of the cortical areas, **12**).

Apparatus and Procedure

The apparatus and technique used in the present study closely parallel those of Bass and Hull (**2**).

General Technique.—The subject was situated in a room across a hall from the one containing the controlling and recording apparatus. The steel cot upon which the subject lay was covered by a blanket stretched over a wooden frame, as in the experiment of Bass and Hull. The cot was located in a corner of the room, with a wooden screen placed at the head-end in such a way as to prevent the subject from seeing anything except a portion of the wall and screen. Visual stimuli were thus minimized.

Interference from auditory stimuli was eliminated by a loud 60 d.v. noise screen provided through a pair of earphones. The intensity of the noise screen could be regulated by an ordinary potential divider circuit inserted in the 60-cycle, 110 volt alternating current line. This was adequate to the extent that the only irrelevant stimulus reported by the subjects was the sound of a class bell.

Stimuli Presented.—Each of the conditioned stimuli used in the present experiment was provided by a vibro-tactile stimulator of the same type as that described by Bass

and Hull (2). The stimulator consisted of a light solenoid with a freely moving metallic core. The core rested on the subject's skin when the current was off, and vibrated against the skin when the current was on. The vibration was at the rate of 60 d.v. per sec. The source of electricity was similar to the source for the earphones. Vibration transmitted through the skin was not perceptible to the fingers at a distance greater than 5 mm from the stimulator. The lack of mechanical spread of vibration was corroborated by the verbal reports of the subjects.

The unconditioned stimulus was provided by an induction shock. The electrodes were nickel-plated discs about one inch in diameter, strapped to opposite sides of the wrist. Current for the shock stimulus was obtained from two one and one-half volt dry cells in series and was passed through the primary coil of a Harvard inductorium. The leads from the secondary coil crossed to the experimental room and to the shock electrodes. The strength of the shock was adjusted so that most of the subjects reported it to be unpleasant but not painful.

A signal key was placed on the bench, near the subject's right hand. By tapping this key, the subject could signal his desire to communicate with the experimenters.

The presentation of all stimuli was controlled by the pendulum of a Dodge photochronograph. The duration of each vibro-tactile stimulus was 435 msec. The shock stimulus, when given, was presented 270 msec. after the onset of the vibro-tactile stimulus and lasted 190 msec. Thus the shock stimulus persisted 25 msec. after the cessation of the vibro-tactile stimulus.

Response Recorded.—Aside from the verbal reports of the subjects, the only reaction recorded was the galvanic skin response.

The galvanic skin response was measured by the method of Féré. The electrodes were two polished silver plates, one inch square. The plates were so attached to a small block of wood that they were about 3 mm apart. The block was held to the palmar surface of the hand by a webbed belt. A block of sponge rubber was inserted between the belt and the electrode block to insure a constant electrical contact with a minimum of discomfort to the subject.

The glavanic skin responses were recorded photographically by a Wechsler recording galvanometer (13, p. 59), constructed by the Central Scientific Co. The exosomatic current was provided by two one and one-half volt dry cells in series. The light beam was maintained on the scale of the galvanometer by a potentiometer which varied the voltage across the circuit in which the subject and the galvanometer were in series. The Wheatstone bridge arrangement provided by this type of instrument was not used. Calibration before the experiment demonstrated that the deflection was for all practical purposes a linear function of the calibrating resistance in series with the galvanometer. During the experiment the resistance in series was the total electrical impedance of the subject's skin.

Five-second intervals were marked on the photographic record by a signal light in the timing circuit of a Harvard pendulum clock. Through a similar signal light, operated by a key switch, one of the experimenters marked the nature of the stimulus on the photographic record.

Subjects.—Thirty-one male students served as subjects in the experiment. They were members of various summer classes in psychology who had been asked to volunteer for an experiment. Only three of the subjects knew anything about the nature of the experiment, and the knowledge of these three was extremely superficial. The records of five additional subjects were not analyzed due, in one case, to one of the vibro-tactile stimulators coming unfastened and, in the other four cases, to the inadequate functioning of the noise screen.

The subjects were divided into two experimental groups on the basis of the placement of the vibro-tactile stimulators. These groups are hereafter arbitrarily referred to as the *Back Group* and the *Hand Group*.

Fifteen of the subjects, ranging in age from 19 to 42 (with a median age of 23), were members of the Back Group. In this group, the stimulators, placed approximately three and one-half to four inches apart, were glued with a rubber-like adhesive about two inches to the right of the medial line of the back, starting at the shoulder and continuing to the waist.

The remaining 16 subjects, ranging in age from 19 to 40 (with a median age of 23), were members of the Hand Group. In this group, the vibro-tactile stimulators were taped at intervals of approximately one inch, the first one being placed above the distal joint of the index finger and the remaining ones extending proximally so that the final stimulator was located on the wrist joint.

Procedure.—Data on the age, weight, height, general health, and previous experience with electrical shocks were obtained from each of the subjects as he presented himself for the experimental session. An inquiry was made with reference to whether the subject considered himself to be calm or excitable. He was also asked if he would object to electric shocks during the experiment.

The palmar surface of the hand to which the galvanic skin response electrodes were later to be applied was cleaned with a piece of cotton saturated with ether. The subject was then taken to the experimental room. Here, members of the Back Group were requested to strip to the waist and remove their shoes. In the case of the Hand Group it was not necessary that any clothing be removed.

The subject was instructed to lie prone, with his arms extended beyond the head of the cot and resting upon a bench provided for that purpose. In such a position, the distance between the hands was approximately thirty-six inches. The subject's head rested on a small pillow.

The noise-screen earphones were adjusted to the subject's comfort. The shock electrodes were applied to the right wrist in the case of the Back Group and to the left wrist in the case of the Hand Group.

In addition, in the Hand Group, the right hand rested upon a large block of sponge rubber, with the second, third, and fourth fingers extending vertically downward into holes bored in the rubber and the extended index finger resting upon the surface. Thus the hand was relatively immobile, yet vibrations could not irradiate mechanically from one part of the hand to another through the hand-rest.

After all adjustments of apparatus had been made, the subject was instructed to signal the experimenters by means of the telegraph key near his right hand if the shock or noise screen were painfully intense or in the event that a disturbance of any sort should occur. The subject was requested to restrict as much as possible any movement, and particularly movement of the hand from which the galvanic skin response was being recorded.

The mechanical aspects of the experiment were directed entirely from the control room. The vibro-tactile stimulators were designated as A, B, C, and D and the possible permutations for the order of presentation were determined. Twenty-four permutations of the type A B C D, B C A D, C A D B, etc., may be derived. Each permutation of four was duplicated symmetrically, so that the vibro-tactile stimulators were activated in the following order: A B C D D C B A, C D B A A B D C, etc. Each of these orders constituted a *tactile stimulus series*. The series were each num-

bered and a different set of five series was used for each subject. The intervals between presentations of the stimuli were irregular, and ranged from 10 to 25 seconds.

Each *conditioning series* consisted of five shocks paired with one of the vibro-tactile stimulators. In the conditioning trials of the Back Group, the stimulator at the shoulder was paired with shock in the case of seven subjects, and the stimulator at the waist was paired with the shock in the case of eight. In the conditioning trials of the Hand Group, half were conditioned to the stimulator at the wrist and half were conditioned to the stimulator at the tip of the index finger.

The sequence of stimulus presentations was as follows:

I. Tactile stimulus series, pre-conditioning.
II. Conditioning series.
III. Tactile stimulus series, test.
IV. Conditioning series.
V. Tactile stimulus series, test.
VI. Conditioning series.
VII. Tactile stimulus series, test.
VIII. Conditioning series.
IX. Tactile stimulus series, test.

The interval occurring between any one conditioning series and the preceding or following test series was irregular, the variation being approximately the same as that between shocks or between tactile stimulation in any given series.

In all instances one experimenter operated all controls. The other was concerned only with indicating to the operator when stimulation was to be applied and marking the nature of the stimulus on the photographic record. No stimuli were given until the galvanometer had ceased fluctuating.

Results

Records were read by one of the writers and later checked by the other. In the event of bimodal deflections, provided the response was continuous, the greatest amplitude of deflection was read. Where there were two discrete responses, the first deflection alone was considered.

The means and probable errors of the galvanic skin response caused by the shock stimuli were $8.93 \pm .89$ for the subjects of the Back Group, and $7.93 \pm .78$ for those of the Hand Group. The units used in this paper are the magnitude of the galvanometer deflection expressed in mm.

Following Bass and Hull (**2**), the point to be conditioned was designated 0, the other points being referred to as 1, 2, and 3 respectively in order of distance from 0.

In the pre-conditioning trials, before any shocks had been presented, the averages and probable errors of the skin

response to the vibro-tactile stimuli at each point were as follows:

	Point Stimulated			
	0	1	2	3
Back Group.....	3.48±.47	3.98±.55	3.77±.38	2.97±.42
Hand Group.....	2.61±.40	2.71±.30	2.41±.30	2.69±.35

The mean differences between the pre-conditioning responses to each pair of stimulators divided by their respective standard errors were as follows:

	Back Group				Hand Group		
	1	2	3		1	2	3
0	−.81	−.61	1.19	0	−.53	.35	−.05
1		.16	2.60	1		.75	1.36
2			2.69	2			−.14

A positive critical ratio indicates that the difference favored the point nearer point 0, and a negative critical ratio indicates that the difference favored the point nearer point 3. Thus, the critical ratio of the mean difference between points 0 and 2 of the Hand Group is .35 in favor of point 0. These data indicate no consistent tendency toward a gradient.

The mean galvanic skin response of each subject to each stimulator is presented in Table I. These averages are for all trials after the initial conditioning series. The means of each subject show few gradients which have no inversions. However, this tendency also appears in the data reported by Bass and Hull (**2**), and by Hovland (**5, 6, 7, 8**), and is evidently a characteristic result of the variability of the galvanic skin response.

The means and probable errors of the Back and Hand Groups appear in Table I, under the individual averages of their respective groups. The critical ratios for the differences

TABLE I

MEAN GALVANIC SKIN RESPONSES TO VIBRO-TACTILE STIMULATORS

Subject		Point Stimulated			
		0	1	2	3
Back Group	1	6.56	5.38	4.06	3.81
	2	2.25	2.25	1.88	2.31
	3	1.88	2.06	1.63	0.44
	4	2.44	1.75	1.25	1.50
	5	4.38	3.63	4.31	4.50
	6	4.44	4.25	4.31	3.56
	7	5.25	4.19	4.75	4.19
	8	2.25	1.63	3.75	2.81
	9	4.69	3.50	3.56	2.81
	10	3.50	2.88	3.50	2.31
	11	4.31	5.44	4.31	6.06
	12	4.63	4.19	4.25	3.88
	13	1.38	1.50	2.81	1.25
	14	3.63	2.38	2.94	2.63
	15	1.75	2.81	1.44	2.25
Mean±P.E.		3.56±.40	3.17±.40	3.26±.35	2.97±.38
Hand Group	16	1.81	1.88	1.25	1.69
	17	5.38	3.25	6.06	5.81
	18	3.75	3.69	3.50	3.00
	19	1.81	3.31	1.50	1.19
	20	2.63	2.75	3.19	2.94
	21	3.13	3.38	2.25	2.69
	22	1.56	0.56	1.31	1.19
	23	2.00	2.50	2.94	4.31
	24	2.25	2.38	2.25	1.94
	25	2.31	2.75	2.25	1.94
	26	2.25	2.00	2.63	1.88
	27	3.00	1.81	2.44	1.00
	28	2.94	3.94	3.00	2.19
	29	1.88	0.56	1.31	0.94
	30	6.38	5.75	4.81	6.00
	31	4.19	3.38	1.19	2.31
Mean±P.E.		2.95±.40	2.75±.30	2.60±.30	2.54±.35

Each column lists the means of the galvanic skin responses of the individual subjects for the point stimulated. Column 0 designates the point reinforced with electric shock; columns 1, 2, and 3 represent points at successively distant intervals from point 0. The means and probable errors are based on the raw data summarized in each column.

between the post-conditioning responses to each pair of stimulators were as follows:

	Back Group				Hand Group		
	1	2	3		1	2	3
0	1.95	1.26	2.10	0	.94	1.46	1.67
1		−.26	1.19	1		.43	.62
2			1.36	2			.29

The increases of the post-conditioning critical ratios over the pre-conditioning critical ratios are due mainly to increases in the correlations between the responses of a given subject

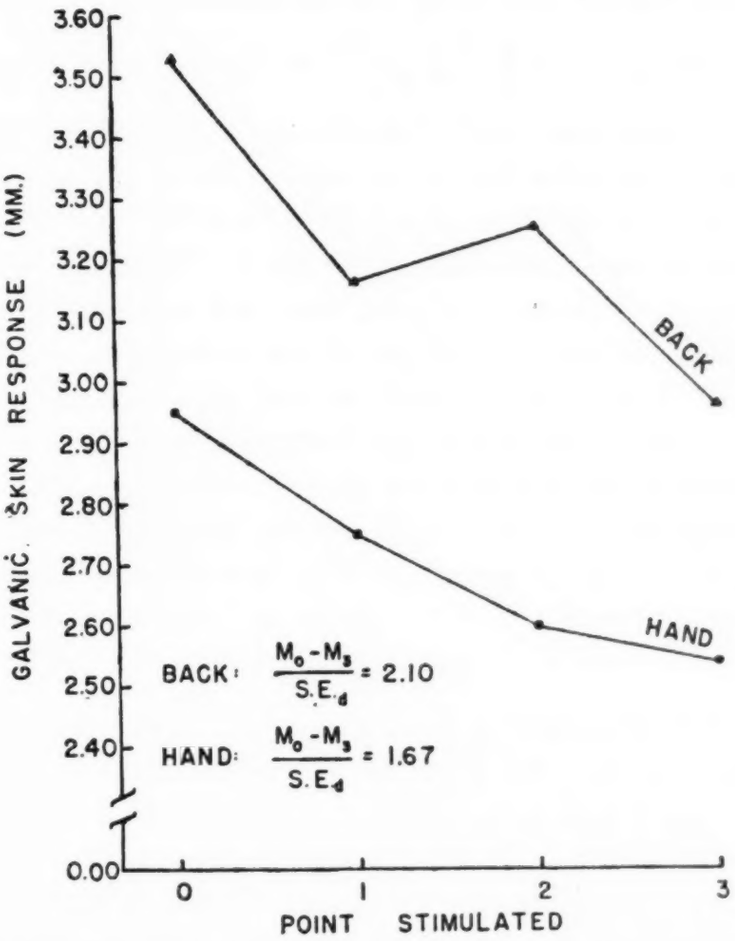

FIG. 1. Back and hand generalization gradients for a galvanic skin response conditioned to vibro-tactile stimulation.

because of the effects of conditioning. Thus, although the mean differences do not change to a great extent, the critical ratios increase. These final means are presented graphically in Fig. 1, and the clear tendencies to a gradient are shown

for each group. The gradients resemble those presented by Hovland more than they do the corresponding gradient presented by Bass and Hull.

The back gradient shows one inversion while the gradient for the hand shows no inversions. This result coincides with the verbal reports of the subjects. The subjects of the Hand Group invariably reported that they could identify the stimulator which was acting. The subjects of the Back Group, on the other hand, could report only that they were able to identify one stimulator over the shoulder and another at the waist, with one or two lying rather unlocalized in between.

The critical ratios $\left(\frac{M_0 - M_3}{\text{S.E.}_d} \text{ in Fig. 1}\right)$ of the two gradients were computed from distributions of the differences for each subject between the mean deflection to the stimulator at point 0 and the corresponding deflection for point 3. These differences were obtained from Table I. This method largely eliminated the effects of adaptation and experimental extinction, besides taking advantage of the correlation between the deflections of a given subject to the two stimulators. The critical ratios of the difference between point 0 and point 3 for the Back Group was 2.10, and for the Hand Group 1.67. The corresponding chances of getting such differences due to sampling error alone would be 2 in 100 for the former and 5 in 100 for the latter.

Discussion

From the standpoint of the present experiment, the important fact is that the gradient for the Hand Group is somewhat less steep and somewhat less reliable than the gradient for the Back Group. If Pavlov's cortical irradiation hypothesis holds, the gradient for the Hand Group should be steeper than the gradient for the Back Group. This would be predicted because the hand irradiation, taking place over a large cortical area, would suffer a greater decrement between successive points that the back irradiation, which would occur over a less extensive cortical area. The results indicate that this is not the case. In fact, any difference in steepness is in favor of the Back Group. If this is verified by further re-

search, the indication is that the hypothesis of cortical irradiation is untenable. The data oppose the notion of static excitatory gradients on the cortex.

Partial refutation of Pavlov's cortical irradiation hypothesis is indicated when Bass and Hull's data are considered with reference to the present knowledge of the sensory-somesthetic representation of the back in man. *Bass and Hull obtained a gradient showing no inversion, in spite of the fact that in man the cortical areas representing the thigh, calf, and foot are interpolated between the areas representing the waist and the buttocks* (**12**)! On the basis of the cortical irradiation hypothesis and in consideration of the above facts of cortical representation, a horizontal or level portion of equal response-magnitude should be found in the calf-thigh half of the gradients obtained by Bass and Hull. When their subjects are separated into two groups according to whether the shoulder or calf point was reinforced, their data do not give the predicted flat portion.

The data then favor a theory like that of Guthrie (**4**) or Wendt (**14**). The likelihood of some complex process involving local-sign and perhaps the subject's perceived 'body image' as the basis for the generalization of tactile stimuli must also be considered. The above theories, however, have difficulty in explaining the results of Anrep (**1**), who found bilaterally symmetrical gradients when only one spot on one side of the animal was conditioned. Considerable data are needed before a decision can be reached in favor of any one of the various theories of the generalization of a conditioned response. In the meantime, the fact that the inversion in the gradient of the Back Group coincided with the subject's verbal reports of inability to discriminate between the locations of the vibro-tactile stimulators favors some sort of theory based on discrimination.

Summary

Conditioned galvanic skin responses were formed to vibro-tactile stimuli in two groups of subjects. The generalization gradient of fifteen subjects for whom the tactile stimu-

lators were placed at equal intervals along the back, from shoulder to waist, may have been slightly steeper than the corresponding gradient for sixteen subjects for whom the stimulators were placed at equal intervals along the dorsum of the hand, from the tip of the index finger to the wrist. Since on the basis of data on cortical representation a steeper gradient for the hand is predicted by Pavlov's cortical irradiation hypothesis the data indicate that this hypothesis is invalid.

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CONDITIONED CARDIOVASCULAR RESPONSES AND SUGGESTIONS FOR THE TREATMENT OF CARDIAC NEUROSES[1]

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Introduction

General Purpose and Setting of the Problem.—The heart, because of its intimate importance in the life span of the individual and the varied disturbances to which it may become subject, has received intensive consideration and study. Conditions relating to purely organic or pathologic categories are fairly well understood, but there remains that vast field of so-called functional disturbances that remain shrouded in mystery, or that at least elude satisfactory solution, especially when viewed from the standpoint of their etiology.

In the discussion based on this investigation no attempt will be made to consider the heart in its anatomical or structural aspects. The study pertained more particularly to features that were felt to have a basic significance in the production of those functional disturbances that have no demonstrable relationship to pathologic conditions of the cardiovascular system.

Cardiac conditioning as an experimental phenomenon interested the present investigator because it was believed that this problem would have a direct bearing on those phases of cardiac dysfunctioning known as the cardiac neuroses.

At the beginning of this experiment the investigator was interested only in the possibility of establishing a conditioned

[1] This investigation was carried out at the University of Wisconsin at the suggestion of Professor Hulsey Cason to whom the author is deeply indebted for his aid and encouragement throughout the progress of the research. He also wishes to express his thanks to Miss Elizabeth Brogdon of the University of Wisconsin, Physiology Department, for the use of her laboratory and equipment, and for helpful suggestions; to Miss Irene E. Beier and Miss Doris V. Wallmo who served as experimenters and assisted in the statistical calculations and analysis of data.

response of excitatory effect on the heart activity. As a measure of this activity the radial pulse was temporarily chosen. The unconditioned stimulus (US) selected was pedaling a bicycle ergometer, to be described later. The reasons for using exercise as the US are as follows: (1) Exercise is the most frequent activity in which an individual engages; (2) it is the most common accelerator of heart activity; (3) it is a more fundamental response pattern than the emotional response; and (4) emotional and faradic stimuli have been employed in establishing conditioned cardiac responses by other experimenters, but none of the many forms of exercise has been used.

Resumé of Literature Relevant to the Problem.—Tigerstedt (**19**) obtained a 'sort of' conditioned cardiac response—*i.e.*, his subjects developed an increase in blood pressure when brought back into a previously exciting situation under which blood pressure measurements had first been taken. This study, however, had for its purpose the investigation of bodily changes in emotions, and not conditioning. The first specific attempt to condition the cardiac response was made by Shipley (**18**) in 1929. He worked with the respiratory response, and the circulatory reflex (pulse) plus other bodily reactions. The unconditioned stimulus was an electric shock and the conditioned stimulus a buzzer. He found that although the buzzer itself served as an unconditioned stimulus for the heart action, the CR tests after training showed that this reaction was more pronounced than in the control series. Shipley concluded that the "heart reaction (pulse) can be readily conditioned," and that although his breathing curves show evidence of considerable fluctuations, the evidence for conditioning is quite reliable and apparent.

Minut-Sarokhtina, Sarokhtin and Turgel (**12**) conditioned the vagotropic (depressive) heart reflex and associated respiratory arrhythmia. The same authors (**15**) established a conditioned vagatropic reflex of the heart by ringing a bell and simultaneously eliciting the Dagnini Aschner or oculocardiac reflex.

Respiratory changes following various stimuli have of

course been studied by many (**2**, **3**, **6**, **13**, **17**), and have been conditioned to signal stimuli by Scott (**16**), Watson (**21**), and Garvey (**8**).

Procedure

In the original plan only one measure, the radial pulse rate, was to be taken. However, while plans of procedure were materializing, it was decided that since exercise represents such diffuse bodily activity it would be practical to develop more indices of its effect. It was therefore decided to take apical heart rate, systolic and diastolic blood pressure, and respiration rate.

A. The Heart Rate was counted by means of a disc stethoscope, with its tambour taped on the skin over the apex of the subject's heart, between the third and fourth ribs.

B. The Blood Pressure, both systolic and diastolic, was taken by a Tycos Sphygmomanometer, with an armlet disc stethoscope over the brachial artery.

C. To measure the *Respiration Rate* a costal respiration pneumograph was used with kymographic recording.

The heart rate and blood pressure readings were recorded during the experiment on specially designed data sheets. (*A*), (*B*), and (*C*) were taken simultaneously, (*A*) and (*C*) for fifteen second intervals and (*B*) every thirty seconds. The apparatus remained attached throughout the entire daily experimental session.

D. The exercises were performed on a recording electrodynamic brake bicycle ergometer (**9**). The exercise selected in this experiment which served as the *original or unconditioned stimulus* was characterized by Kelso and Hellebrandt (**9**) as 'violent.' A speed of three amperes and a load of six volts were used, in other words, the subject pedaled at a speed of 88 r.p.m., working at a rate of 1,031 Kgm. per minute.

E. Substitute Stimulus. An electric buzzer about one yard above the subject's head served as the substitute or conditioned stimulus. The current in this circuit was checked at regular intervals throughout the experiment in order to control the magnitude and frequency of the buzzer's vibrations.

F. Subject's Regimen. The subjects were asked to lead as regular a life as possible, retiring and getting up at the same time every day. No strenuous exercise for four hours before the time of the experimental session was permitted. The use of alcoholic and caffeinated drinks was limited. None of the subjects used tobacco in any form. It was also suggested that eating be done at regular times and of approximately the same quantity, with no afternoon lunches.

Three experimenters were needed at all times. The experimenters gave the subject no cues which would prejudice the results. The subjects were blindfolded by means of cotton stuffed behind their glasses and all communications between the experimenters were in pantomine. All subjects were unacquainted with the plan and purpose of the experiment.

Detailed Procedure.—In this experiment there was a total of three subjects. Each subject came daily, including Saturdays and Sundays, at 4:15 P.M., at which time the instruments were attached. The whole experiment was carried out, complete in every detail, on one subject first. The individual experimental sessions began at 4:30 and lasted until approximately 6:00 P.M.

i. *Natural resting state.* Immediately after the instruments had been attached, S was seated on a high stool directly behind the bicycle ergometer with his left hand resting on a table to enable the taking of blood pressure readings. The respiration and

heart rate were recorded every fifteen seconds, for that interval, and the blood pressure readings were taken every thirty seconds. These measures were taken continuously until S had reached as near as possible his normal heart rate and blood pressure readings and until four or more successive heart rate measures were the same and two or three blood pressure readings did not vary more than 2 mm. of mercury. This norm is called the *stability criterion.* This procedure (i) was the first part of every experimental session and required from seven to fifteen minutes on different days. The purpose of this procedure was to establish norms for the day and produce a standard against which other measurements for the day could be compared.

ii. *Control Test: influence of buzzer.* With S still seated on the stool, the buzzer was presented for one minute and the three measures were taken continuously from the beginning of the buzzer until the stability criterion was reached. The purpose of this procedure (ii) was two-fold: to give an indication of the unconditioned effect of the buzzer, and to allow S to become adapted to it. This procedure required from four to fifteen minutes on different days.

iii. *Control Test: influence of exercise.* After the stability criterion had been reached in procedure (ii), the subject's blindfold was removed, and at a spoken signal he mounted the bicycle ergometer. The removal of the blindfold was necessary in order that the subject might observe the meter by which he was to control his speed. At a signal, the subject began to pedal at the previously described speed and against the chosen load for one minute. At the end of this one minute exercise period, S resumed his seat on the stool immediately behind the ergometer. The blindfold was replaced and approximately fifteen seconds after exercise the three measures were again taken continuously until the stability criterion was reached. This procedure (iii) took from thirteen to thirty-five minutes on various days.

With the first subject procedures (i), (ii), and (iii) were continued until he became habituated to the total experimental situation and adapted to the buzzer. After this pre-training or adaptation series was completed, the training sessions were begun on the following day.

The procedure during the training sessions in addition to procedure (i), natural resting state of S, which was always the first part of each experimental session throughout the pre-training and training series, consisted of:

iv. *Conditioned response training.* In this procedure the exercise was combined with the buzzer for one minute. The procedure was the same as (iii) with the three measures taken until the stability criterion was reached. This constituted one conditioned response training repetition. From two to four of these CR training repetitions were possible on different days, dependent on the subjects' recovery period.

v. *Conditioned response test.* This CR test, buzzer alone exactly as in procedure (ii), was given after the first three CR training repetitions had been given. After this first CR test, it was repeated at irregular intervals throughout the series of CR training repetitions.

With the first subject the procedure as outlined above was carried out. The procedures for the remaining two subjects were the same with the exception that (iii), control test: influence of exercise was omitted. This was done because after a careful evaluation of data from the first subject it was apparent that this control test was unnecessary and lengthened the procedure considerably.

Results

In order to analyze and study the data the results of the individual subjects were graphed. These graphs were included in an original write-up on file in the University of Wisconsin Library, but being quite numerous, thirty-four in all, no attempt will be made to include them in the present article. Rather it is felt that an accurate description of the results, as indicated by these graphs, would serve to convey a fairly complete and comprehensive picture of the findings. These results, as well as a description of individual characteristics, will be discussed separately for each subject.

Subject 1. This subject's reactions have been found to be more variable and less stable than those of subjects 2 and 3. His normal heart rate (approximately 88 beats per minute) was above the average for males of his age and weight. His respiratory rate was from four to six inspiration-expiration cycles faster than the respiratory rates of the other two subjects. The effects of exercise on his reactions were also more intense and enduring. It is well to point out that his apparent instability of cardiac response as well as the rapidity of the respiratory rate might be a residuum of rheumatic fever from which he suffered as a child.

With S-1, it took ten pre-training sessions to completely habituate him to the total experimental situation and adapt him to the sound of the buzzer. Analysis of this subject's graphs indicated the following:

The conditioned cardiac response took the form of acceleration of the heart rate. It was also evident from the results that as training progressed, the conditioned response became consistently greater as well as more enduring.

Conditioning of the blood pressure response was not so apparent as that of the heart rate; however, after a careful examination of the records and graphs it is probably safe to conclude that conditioning did occur. This conditioning was in the form of a disturbance of the blood pressure, *i.e.*, rapid rises and falls. The blood pressure also indicated increased variability as re-enforcement continued.

With regard to respiratory rate, conditioning was not

apparent but this response showed considerable fluctuation. This is in line with the findings of Garvey (**8**) and Shipley (**18**).

Subject 2. Using the modified procedure, *i.e.*, omitting procedure (iii), three days with fourteen presentations of buzzer alone, were necessary to adapt S-2 to the sound of the buzzer. This adaptation was far more reliable and complete than with S-1. On the whole S-2's reactions were more stable, less intense, and more consistent than the reactions of the first subject.

Analyzing this subject's graphs, we find that they also indicate conditioning. The conditioned heart rate response was of a different type. With S-2 we have a conditioned arrhythmia response rather than a simple conditioned acceleration. The subject's heart reaction seemed to simulate that clinical variety of psychoneurotic cardiac manifestations described as Premature Contractions—*i.e.*, the response was characterized by 'skips' or 'flops.'

The blood pressure response again indicated a conditioned disturbance and is similar to the previous subject's reactions.

The respiratory rate, as in S-1, showed neither consistent nor reliable evidence of conditioning.

Subject 3 was far the most stable of the three subjects, and his reactions, though none the less definite, were less severe and less enduring than the reactions of the previous subjects.

The heart rate of this subject showed a still different type or pattern of conditioned response—*i.e.*, with the CR test, the heart rate dropped abruptly below the subject's previously determined rate for the day. This drop lasted for about fifteen seconds, after which the rate rose rapidly, remained accelerated as with S-1, then gradually returned to normal. Here too as with the previous subjects, there is evidence of increasing intensity and duration of the CR as re-enforcement continued.

The blood pressure and respiratory responses again showed reactions more or less similar to those of the other subjects.

Discussion

Cardiologists and psychiatrists generally refer to the cardiac neuroses as 'conditioned irritability to normal stimuli.' Dry (**7**) suggests the following circumstances in which such conditioning may occur: (1) Exhaustion states, such as those following intercurrent illnesses; (2) chronic nervous fatigue; and (3) the known presence of some form of organic disease. To these might be added situations with strong emotional qualities. Dry further states, "One should determine what symptoms are neurogenic manifestations and what conditioning factors are present in the individual." This experiment represents a partial fulfillment of the desires of cardiologists and psychiatrists for an investigation of basic conditioned heart phenomena. Such research is needed to furnish a starting point in the treatment and unconditioning of cardiac neuroses.

Menninger (**11**) from a review of the literature concludes that "Between 20 percent and 50 percent of individuals who consult physicians for cardiac disorders show no organic lesion." Other estimates of the prevalence of the cardiac neuroses range from 26 percent to 65 percent. Cardiac neuroses have been classified in numerous ways. Wyckoff (**22**) classifies them as follows: (1) Fatigue neuroses (neurasthenia); (2) introspective neuroses (hypochondria); (3) anxiety neuroses; (4) substitution neuroses (hysteria); and (5) obsession neuroses (psychasthenia). Wahl (**20**) describes the following common clinical varieties: (1) Premature contraction (extra-systoles); (2) neurocirculatory asthenia (effort syndrome or soldier's heart); (3) paroxysmal tachycardia; (4) pain (pseudo-angina); (5) cardiac neuroses (suggestion); and (6) other functional disorders (arrhythmia, dyspnea, etc.).

It might be well to add that these functional heart disorders are usually far more disabling, and the age group affected with cardiac neuroses is on the whole from ten to twenty years younger than those with organic heart disturbances.

It is not our intent to suggest that all functional disturbances or even all psychoneurotic cardiac manifestations can be

explained purely in terms of conditioned response concepts. Rather, it is the purpose of this article to demonstrate a type of cardiac conditioning and to suggest that cardiac conditioning, and conditioning in general, may make for a fuller understanding of the functional cardiac diseases and offer a possible method of treating these disorders.

That the cardiac response can be conditioned has been shown by this and other experiments. That maladaptive conditioning from emotional and other experiences may occur is also accepted. Anderson, Parmenter and Liddell (1) have recently shown the development of an experimental neurosis and an accompanying cardiac disorder in sheep, the cardiovascular manifestations being marked tachycardia and arrhythmia. In the present experiment the conditioned heart rate assumed different patterns with the different subjects, and these patterns remained characteristic—*i.e.*, tachycardia with S-1, arrhythmia with S-2 and a combination of the two with S-3. These manifestations do not lead to the conclusion that they are experimentally induced cardiac neuroses, but may indicate predispositions, of the various subjects, toward a rather specific neurotic heart dysfunctioning.

Remembering the prevalence of the cardiac neuroses we realize the need for some more adequate method of treatment for these disorders. Reiterating the opinions of cardiologists and psychiatrists that these functional disturbances represent 'conditioned irritability to normal stimuli' we suggest, as a tentative hypothesis, that some of the CR techniques might have therapeutic uses in the treatment of these functional disturbances of the heart. Therefore, at this point, we consider this possibility along with a therapeutic procedure that might be used with individuals suffering from such disabling disturbances.

After it has been adequately determined that no organic heart lesion or actual pathological condition of the cardiovascular system exists, and after the conditioning factors, conditioned stimulus or stimuli have been determined, two possible techniques readily suggest themselves, 'reconditioning' and unconditioning.

1. '*Reconditioning.*' Reconditioning in this sense referring to further modification of the established CR by association of its stimulus with a new stimulus capable of reducing the pulse rate—*e.g.*, the Dagnini Aschner reflex, sedatives, rest and relaxation, etc. The original CR, which represents an accelerated or disturbed heart response, if associated with a vagotropic or depressive heart response, will result in heart action, it may be theorized, which will be something of an average of the two and approximately normal. The success of Maier's work (**10**) with rats, conditioning neuroses and curing them by reconditioning, supports this type of therapeutic procedure.

2. *Experimental unconditioning* (*extinction*). In this type of procedure the conditioned stimulus might be presented until the response is 'extinguished' or suspended. It is realized that this Pavlovian law is still much in debate and that it may not apply to all phases of human conditioning. However, the evidence in the main seems to indicate that if unconditioning is continued beyond and subsequent to spontaneous recovery, the 'extinction' or suspension may become permanent. It is necessary to remember in regard to experimental unconditioning the role played by verbal activities, as shown by Cason (**4**, **5**), and the importance of set and attitudes as evidenced in Razran's study (**14**).

Realizing that the above type of treatment does not represent a panacea for the cardiac neuroses, prophecies as to the outcome of such therapeutic procedures may be dispensed with. Though the psychological and psychiatric implications proferred are but a brief outline of the possibilities, they do represent a starting point that may result in a new and clearer theory and more adequate treatment of those phases of cardiac dysfunctioning, the cardiac psychoneuroses.

Summary and Conclusions

The present investigation studied general human cardiovascular conditioning and the theoretical implications such conditioning might have for the study, treatment and subsequent cure of the functional cardiac diseases, the cardiac psychoneuroses.

The principal results of the study were as follows:

1. The cardiovascular response can be conditioned to a buzzer, using exercise as the original or unconditioned stimulus.

2. The conditioned response was present in all three subjects after three CR training repetitions.

3. The conditioned heart rate responses assumed various patterns typical of individual subjects. The patterns or types of conditioned responses to the buzzer did not, on the whole, resemble the original unconditioned response to the buzzer before adaptation.

4. The conditioned responses showed progressive reinforcement through training—*i.e.*, they became more intense and enduring.

5. The type of procedure used gave no clear evidence of the occurrence of a conditioned respiratory response.

Since these conditioned reactions showed a marked similarity to the cardiac neuroses, a treatment of these functional heart disorders, by means of 'reconditioning' and unconditioning was suggested.

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STUDIES IN HIGH SPEED CONTINUOUS WORK: V. PAIN, BLOCKING AND TIREDNESS

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A previous paper in this series dealt with motivation and hedonic tone—subjective factors which affect the output of continuous work. There are other factors, subjective in part at least, which may be studied in a semi-objective fashion. For this purpose, during an experiment on continuous tapping (1) records were taken of Ss exclamations, statements and replies to questions, and of such objective reactions as his cramping, blocking, dropping of stylus, etc. At the conclusion of the work period, S supplemented the records of Es by rather lengthy introspective notes.

Naturally the listing of the number of times that Ss remarked on the pain they were suffering, or the tiredness they experienced, is not an accurate gauge of the pain or fatigue they endured. At best only a rough idea may be gleaned of their feeling tone during the course of the work, for the procedure would vary somewhat from individual to individual, though it may be expected to be fairly constant during the testing of any one individual. Despite the inadequacy of the method we do obtain a record of the subjective state that could not otherwise be gathered. Thus Table 1, which lists the frequency of the reference to pain and its location, shows considerable variation within the group. It is to be noted that pain seems to centre in the arm, and to spread with diminished frequency (and intensity), to the distal muscles, involving the neck, head, and even in some cases the whole body. Nearly every S experienced pain in the arm, shoulder and finger, most of which was muscular, though blistering and surface irritation often occurred in the finger and forearm.

In Table 2, under the heading Feelings of tiredness, an attempt was made to list all references to and objective indica-

TABLE 1

FREQUENCY OF REFERENCES TO PAIN

Location	Frequency	No. of Ss
Index finger	15	3
Finger	48	13
Thumb	3	3
Wrist	9	6
Hand	15	8
Forearm	24	8
Arm	146	14
Whole arm	5	3
Shoulder	101	12
Elbow	28	10
Neck	10	2
Head	3	3
Body	5	3
Pain	51	14
Totals	463	102

tions of fatigue, such as sweating, sighing, etc. Roughly three states may be made out: feelings of elation, indifference and depression. These states are not to be confused with hedonic tone which was separately rated, for the feelings of fatigue constitute only one of the components of hedonic tone. A broad interpretation must be given to these objective indica-

TABLE 2

FREQUENCY OF FEELINGS OF TIREDNESS

A. Subjective States

Elation			Boredom			Depression		
Cheerful	17	8	Lazy	5	2	Gloomy	4	4
Resists slowing	5	2	Sleepy	6	3	Irritable	11	6
Time flies	4	2	Indifferent	8	4	Angry	7	3
Feelings satisfactory	24	10	Bored	3	2	Discouraged	4	3
			Time drags	2	1	Dejected	7	6
			Wants to stop	17	8	Tired	92	14
Totals	50	22		41	20		125	36

B. Objective Signs

Actions			Appearance		
Sighs	4	4	Face red	3	3
Swears	16	7	Pale	1	1
Sweats	8	5	Sick	2	2
Bites lip	2	1	Groggy	2	2
Eyes shut	2	2	Dizzy	3	3
Holds head	7	5	Hot	7	5
Restless	8	5			
Headache	2	1			
Grinds teeth	1	1			
Totals	49	35		18	16

The first number is the frequency; the second, the number of Ss showing the reaction.

tions, for they are not all clearly significant of fatigue, and probably are more indicative of physical discomfort. Points worthy of note are the following: the prevalence of boring and depressing reactions over the cheerful ones; the number of Ss who wanted to stop, but who refrained from so doing on account of their own determination or the urgings of Es; the references to the uneven flow of time, which speeded up with elation and dragged in distress; the explosiveness of the reactions of some Ss, and the pronounced physical distress of others, as evidenced by their paleness, dizziness, etc. The objective signs in this table, and the introspective notes of Ss leave us no doubt as to the strenuous nature of the task.

TABLE 3

FREQUENCY OF BLOCKING

Numbness	42	14	Misses plates	11	6
Cramps	44	7	Drops stylus	25	7
Blocking	224	14	Relaxes	1	1
Inhibitions	20	5	Pauses	5	4
Spasmodic	9	4	Automatic	2	2
Irregular	4	3	Taps hard	24	7
Wild	17	5	Effort	12	6
No control	15	6	Concentrates	26	6
Spurts	21	7	Shock	8	3
Totals	396	65		114	42

Table 3 lists the overt reactions that deal with efficiency or lack of it; they are grouped under the broad heading of blocking, but they also include numbness and irregularity of movement. In the second half of the table are indicated the variations in intensity of effort—the additional concentration or gripping of the stylus that is often a prelude to blocking. Numbing and blocking were experienced by all Ss, and irregularities of rhythm were common. In this table especially is it evident that the frequency with which a certain phenomenon is listed is only a clue to the frequency of its actual occurrence. Thus every S frequently spurted; yet spurting is listed for 7 Ss only, on an average of 3 times each, for in these cases the spurting was intense and prolonged. Other phenomena, such as dropping of stylus, were duly reported, as it was such a marked deviation from normal procedure, being due to the severe numbness of the hand, rather than to carelessness.

The listing in Tables 1, 2 and 3 of the frequency of a given reaction and the number of Ss from whom it was reported enable us to form an idea how widespread was the reaction within the group. Often the same type of reaction was labelled in different ways; thus irregularity of tapping rhythm, which is listed in 5 ways in Table 3, must not be thought of as being confined to a few Ss. On the other hand certain specific reactions, such as the occurrence of shock, was felt by only 3 Ss, and was listed every time that it did occur.

Table 4 gives the frequency of occurrence of each of the

TABLE 4

FREQUENCY OF OCCURRENCE OF PAIN, BLOCKING AND TIREDNESS PER HALF HOUR INTERVAL

Interval	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Total
Pain	49	28	31	34	26	29	39	29	42	50	42	36	12	9	7	463
Tiredness	7	3	9	10	8	4	2	13	10	9	9	7	1	—	—	92
Blocking	33	30	25	27	28	27	18	16	20	18	26	8	5	2	3	286

Note: Only 4 Ss went beyond the 12th. interval.

three main variables. The half hour was chosen as the temporal unit, as the 15 min. periods are too short to yield reliable figures, and the hour periods smooth out the variations too much. To be noted in the second half hour is the diminution of pain and tiredness, after more than an average amount of all three variables was shown in the first period. From the third to the ninth half hour pain and blocking remain fairly constant, till towards the end of the working period the protocols show an increase in all three variables. Thus Table 4 correlates well with the actual experience of Ss as indicated by their introspective remarks. The first half hour was painful and laborious, and was followed by a half hour period relatively free from difficulty. Then S settled down to the long grind without much variation in feeling tone till he tired badly and experienced more pain and blocking as the end approached.

A previous paper reported concomitance between hedonic tone and output (**2**). Since the introspective remarks indicate long term fluctuations in hedonic tone parallel the frequency

of occurrence of the subjective factors of pain, blocking and tiredness (in the expected direction of unpleasantness), an attempt was made to correlate the frequencies of these factors with output. There was no evidence whatever of correlation, whether quarter hour, half hour, or hour time intervals were chosen, partly due to the relatively small number or remarks in the protocols, and partly due to the small variation in output during the course of the task.

Table 5 lists the frequency of occurrence of pain, tiredness

TABLE 5

AVERAGE FREQUENCY OF OCCURRENCE OF PAIN, TIREDNESS AND BLOCKING FOR EACH S PER HALF HOUR

Subject	Pain	Tiredness	Blocking
1	3.92	2.67	2.92
2	1.36	0.54	2.55
3	5.46	0.08	0.92
4	1.33	0.17	0.23
5	2.22	0.91	1.07
6	1.71	0.17	1.27
7	2.34	0.33	2.75
8	1.33	0.00	0.06
9	1.17	0.42	3.00
10	2.00	0.20	4.20
11	1.17	1.09	0.82
12	9.72	0.25	2.33
13	1.75	1.10	0.30
14	2.56	2.00	2.20

and blocking for each S. It is to be noted that there is a wide variation in the number of feelings experienced, if frequency may be taken as a rough clue to their actual occurrence. From this table intercorrelations were calculated by the rank difference method for the 12 Ss of Experiment *A*, and are given in Table 6. Added variables were the average

TABLE 6

INTERCORRELATIONS OF SUBJECTIVE FACTORS WITH OUTPUT

	1	2	3	4	5
1. Pain					
2. Tiredness	−0.05				
3. Blocking	0.25	0.34			
4. Test rate	0.50	0.10	−0.07		
5. Asymptote	0.11	0.77	0.44	0.43	
6. Ninth half hour rate	0.21	0.07	0.18	0.87	0.39

rate, the value of the asymptote of the hyperbola of best fit of the output curve, and the 9th half hour average; as was stated in a previous paper (**3**) they are fair measures of the working rate toward the end of the experiment. Owing to the small number of Ss, and the rough mode of ascertaining the feelings, the correlations are not particularily trustworthy, and they yield only a first approximation to the degree of concomitance of the variables. Of interest is the fact that pain does not correlate with tired feelings, though it does slightly with blocking; also that blocking and tiredness correlate to some degree. In general the three variables studied correlate little with output, no matter how it is measured. The moderate intercorrelations of the three measures of output give us a hint as to the degree of dependence that may be attached to our semi-objective measure of pain, tiredness and blocking. Correlation is to be found in the expected direction between output and subjective factors for the individual, but not in a time series for the group, since the pronounced fluctuations of all variables, occurring in different sequences for different Ss, smooths out all averages and no general trend can be obtained.

Once again it may be stated that the preceding tables, though far from accurate in their portrayal of actual conditions, at least do sketch, in preliminary fashion, and in a semi-objective way, those reactions of Ss which may be called subjective. The only other clue that we have of these reactions are the protocols and the introspective remarks of Ss, written shortly after the working period. The introspective remarks are quoted at some length, for better than any tabulation they give us a picture of the actual feelings of Ss who participated in the experiment; their sufferings, their annoyances, their irritations, their elation, their helplessness in the face of inhibitions and blocking, and the deadening effect of fatigue.

Certain points are particularly worthy of note; thus the early onset and transient character of pain is quite apparent. Like the work output it is periodic, though probably it has a much shorter period. It has a cumulative effect also, not as

sharp, localized pain, but as a throbbing and numbness, which spreads till it affects most of the muscles if not the whole of the body, when it acts as an anæsthetic, taking away the edge of the sharp, shooting pain, and blurring its precise localization. Only when new muscles are brought into play by a change in tapping routine or when attention is focused on some particular muscle is there a resurgence of localized pain. With the onset of sharp, definite pain the output is momentarily diminished, and often is followed by a compensatory spurt. Dull, diffuse pain, which persists for some time, numbs the muscles, and makes for an abstracted attitude, a steady rhythm, and the maintenance of the output close to the effective maximum.

Blocking occurred frequently for every S during the course of the task, particularily at the outset and towards the end when S was thoroughly fatigued. It was evidenced by a pronounced hiatus in the rhythm, which took up the time of from 4 to 8 taps. When the interruptions were longer than this, particularily when there was a complete inability to control the movement, the term inhibition was applied. In such cases the motion ceased completely or there was a series of wild, random movements, aimless circlings, and inability to move the arm to the opposite plate, much to the disgust and irritation of S and to the amusement of Es. Blocking was frequently preceded by increased pain, spasmodic cramping and prolonged tension. Particularily after a rest, when S tried to spurt, without gradually building up increased speed, or when disturbances of rhythm took place, due to lapses of attention or to distracting stimuli, the smoothness of motion faltered and blocking occurred. Sometimes towards the end of the task peculiar illusions of movement occurred, after S had settled down to a monotonous, even rhythm, during the course of which his actions had become almost automatic and he had adopted a preferred mode of peripheral fixation of one plate (generally the far one), with a positive swinging movement to that plate and a relaxed swing back to the other. Often his fixation would suddenly and involuntarily change, after the fashion of rivalry in perception, his rhythm would

be lost, and wild, circular movements would develop. S could only emerge from this situation by deliberately and forcibly increasing the tension, or by tapping the same plate several times in succession, thus definitely breaking the rhythm. This phenomenon, reported by 6 Ss in their introspective notes, was characteristic of the last stages of the task, when S was thoroughly fatigued.

Spurts to high speed levels could be made quickly only by intense concentration and pronounced tension; as a rule they were unproductive for the ensuing blocking caused a compensatory decrement. On the other hand the highest speed levels were attained by smooth, effortless, rhythmic tapping with a relatively slow acceleration, which was followed by a long, slow decrement without much blocking.

From the introspective records of tiredness we note that, like pain, it is episodic, transient and periodic. Periods of progressive lassitude may be followed by brief intervals of relative freshness and freedom from fatigue; in general they are synchronomous with marked increments of output, freedom from blocking, or other incidents that raise the hedonic tone. But most of all tiredness is cumulative. The numbness seems to spread from the muscles of the arm to the whole body, and affects the mental attitude, causing abulia and mental inertia, so that S seems to be satisfied with an automatic reaction at an effective maximum. Strong mental effort, with renewed motivation based upon specific and ever changing goals, must be used to induce S to avoid this automaticity and to strive for an absolute maximum. Towards the end of the task, when fatigue becomes more and more apparent, there is an increased irritation, fretting and solicitude for the coöperation of Es. All incentives, formerly effective, lose their stimulating power, and the thoroughly wearied S responds most of all to the prospect of the approaching conclusion of the task; his feelings brighten and he invariably winds up with a prolonged end spurt.

Excerpts from Introspective Notes

Pain

S3.—Pain became very intense in shoulder and upper arm muscles in the first minute of the run. For a period of 15 mins. this pain became more and more intense as the minutes passed. During these first minutes I developed what may seem at first glance to be a peculiar type of motion. Briefly it was as follows: I would be tapping quite smoothly (pain in shoulder intense), then I would spurt, still smooth tapping, pain would become still more intense, then there occurred a momentary block, lasting perhaps a second, or a fraction of a second. . . . At this stage (conclusion of first 15–20 mins.), pain in the upper muscles of the arm began to subside; as a result I began to feel more cheerful towards my fellow-man in general and to the project in particular. My muscles were beginning to adapt themselves to existing conditions under which they were being subjected. As a result, there occurred a period in which I could concentrate with no interference from pain. However, at this time, while there was no pain, a dull throb persisted in my arm. I was not at all bothered by my elbow or forearm. Because I was gripping the stylus loosely, my fingers were at their ease—no pains or cramps. Further, I was mentally alert at this time, and I was in a position to concentrate to the best of my ability. For a period of about 15 mins., therefore, I tapped at a greater than average speed, mostly smoothly. It appeared at that time to me that my mental being had become reconciled to any pain that might be in my arm; thus I felt no pain other than a dull numbing throb. However, whenever I was reminded of my arm, or E would ask how it felt, my arm would to some extent increase in pain, or so it seemed. During this period also I felt unpleasant. This was due to the pain I had experienced. Also I had not yet become reconciled to the extent of my task. From this time on whenever Es recorded that my arm or wrist was sore, this soreness was not of the intense pain type, but rather a dull throbbing pain. As I was reconciled to pain, I do not believe that it affected my speed very much.

As time passed (it passed very swiftly), while my arm did not pain, nevertheless it tended to become heavy, wooden, partially wooden, partially numb, especially the upper arm and shoulder. Forearm felt a bit numb. I mean that my arm did not have that 'minute' feeling which in action could be associated to words such as 'precision,' etc. For instance, my arm would have been useless, say, for a game of billiards. . . .

S4.—Towards the end of the first hour all blocking had disappeared and the arm gradually deadened to the work. The light pain that I experienced in the forearm gradually turned to a numbed feeling. The dull ache of the muscle slowly traveled up the arm. At the third hour it had reached the shoulder where it seemed to spread to some of the neck muscles. As the seventh hour drew near the ache settled in the shoulder blade, where, with the usual movement it didn't bother me, but any quick stretching made me very conscious of its soreness. . . .

When I rose from my seat at the finish I wished never to see the apparatus again. The relief of having the experiment over meant much and I was glad to leave the laboratory. In going downstairs I noticed a pain in my left leg. Other after effects were not as great as I expected. The forearm swelled through friction on the table. After a sound sleep there was a slight stiffness which lasted for two days.

S8.—At about the five min. mark a pain started in the muscles of the forearm and traveled up my arm to the shoulder, and towards the end of the experiment even to my head. The only pain, however, that really did bother me was a burning pain in the muscles of my forearm. After the fourth hour the pain was so severe that I placed my left hand under it, and since this eased the pain, I maintained this position for the

remainder of the experiment. . . . The after effects were that, due to an aching and swollen arm, I got very little sleep. The stiffness and ache in the arm continued for three days afterwards.

S9.—By the end of the second hour my shoulder was quite sore and I was doing my best to ease it by shifting the position of my arm. This soreness was superseded by an intense pain in the muscle of my forearm on which my arm had been pivoting on the desk and this pain continued to bother me throughout the experiment. I was very much surprised to find the fourth hour approaching and could hardly realize I had been going so long. . . .

S7.—In the first hour I experienced pain in my shoulder, arm and fingers. I was bent on reaching the 300 tap per sec. mark especially after convincing myself that it could be done. My muscles throughout my body were more tense, and the harder I tried for the maximum, the worse I felt. At this stage I commenced to sweat and was encouraged and annoyed by Es. The pain in my arm was beginning to worry me so I tried various ways of avoiding it. About an hour and a half after starting my lower arm was numb and I seemed to be tapping more regularly. Sometimes pain seized my upper or lower arm, but only for a short time. . . .

S10.—I skinned the finger next to the little one. My middle finger became sore along the side where it touched the stylus. I found difficulty in holding the stylus and lost many taps in trying to change the position of the stylus in my hand. I could not keep a fast pace for more than a minute because of my fingers, though my arm was fine and my swing steady. . . .

S12.—At the end of about an hour the under part of my forearm began to get very sore from the friction caused by rubbing against the table. (Note! This was not muscular pain.) In another hour it was burning all the time, and by the end of the experiment the skin was partly scraped off, and jots of blood appeared. So whenever I tried to speed I had to overcome this pain, a resolve that I could not keep up for long, so really a good many times I was not going as fast as I was physically capable of.

S6.—In the third hour my forearm became very sore, and when I spurted my shoulder began to ache. The entire arm was gradually tending to become numb. But as the time passed my arm became very sore, and I imagined that I could feel it slowly swelling. Blocking started again and with it a marked distaste for the work arose within me.

Immediately after the rest period I found it was quite difficult to start to use my arm again. But after two or three minutes of the resumed work the arm once more became an integral part of me and quite a noticeable warming up effect was produced.

I now began to feel hungry and also desired a bottle of pop. I assuaged my hunger somewhat with a chocolate bar, and the pop revived my flagging spirits greatly. My arm gradually became very numb and as the fifth hour progressed I lost almost all sense of feeling. Then cramps appeared in my forearm and these gradually became very definite. I began again to lose my grip on the stylus occasionally. But inwardly I felt much better, taking a certain pride in the increasing evidences of the fatigue of my arm. At 7.30, after five hours and fifteen minutes, I was permitted another rest. During this rest period my arm pained greatly when I moved about.

After five minutes I started again. My forearm was very tender and had become surprisingly sensitive, to such an extent in fact, that I again placed the scarf under it. The work was very difficult to start again and I had a very strong impulse to quit. But after a few minutes the arm felt much better. About eight o'clock the pains began to shoot from wrist to shoulder. I became very apathetic to my surroundings. At the entrance of the janitor for the purpose of closing the window I scarcely raised my

eyes. As the arm became very sore and developed a sickening ache I ate another chocolate bar (my second), but this did not help at all. I was feeling steadily worse as time went on and it required some determination to keep going. After six hours and twenty minutes I felt forced to take another rest. During the rest period my arm became very sore, and I was unable to raise it above my shoulder.

After five minutes of rest I resumed my task. The resumption was even worse than I had anticipated. Only the fact that S4 had lasted seven hours kept me going. I firmly believe that the rests, at least in my case, were unremunerative. My feelings immediately after rest periods were, if anything, worse, and certainly not better. I felt just a little sick, which condition was no doubt assisted nobly by my varied diet of pop, peppermints, chocolate bars and candy in place of my usual supper. On the completion of seven hours and five minutes for good measure, I relinquished my task, and wended my way homeward with a feeling of relief. My arm was very sore and my only desire was to go to bed.

S13.—At various periods in the experiment I suffered from recurring aches and pains, particularly in my shoulder, occurring quite regularly after each initial spurt and slowing me up considerably. Gradually these shoulder pains would cease and be replaced by a slightly tired sensation in the shoulder and upper arm.

After about three and one half hours these pains ceased for a time to be individual and my whole arm felt sore. This sensation however disappeared quite rapidly only to return in a more severe form about half an hour later. The intensity of the pain decreased more slowly this time and was followed by a long period in which the muscles felt almost numb. After five hours of tapping the arm as a whole again became quite sore and remained in this state for half an hour. By this time also the effects had spread beyond my arm, and I felt a general sense of weariness.

The five minute rest period preceding the half hour run gave me a taste of what I was to experience following the completion of the experiment, as it was sufficiently long to allow the muscles to stiffen and a certain numbness to affect my arm and shoulder.

The half hour run began at 8.15 P.M. My entire arm was sore by 8.37 P.M., and my wrist was aching badly. By 8.43 the pain in my shoulder had increased and my fingers and hand were beginning to ache.

Immediately following the conclusion of the experiment I attempted to write my name with rather ludicrous results (considering that I was unable even to pick up the pencil with my right hand). There was almost a complete lack of control and I had the curious sensation of finding that I could write more legibly with my left hand than with my right.

After a few minutes a dull throbbing ache similar to a severe case of 'growing pains' rendered my right arm almost useless and it was with difficulty that I put on my coat in preparation for my walk home. My forearm was swollen and sore to touch from the pressure and friction it had encountered in its contact with the table. However these conditions were only temporary, and the following morning only a slight tenderness in the muscles of my forearm remained.

Blocking

S2.—I started the task with a glove on and tended to pivot my swing from my elbow, which rested on the desk. In the first 5 or 10 mins. certain muscles began to ache and before an hour was half over my elbow was sore and I abandoned the elbow swing, using a full arm motion, thus avoiding the sore spot and increasing my speed.

After an hour run, the motion became quite automatic and at one time my arm swung over to another plate, opposite the one which I intended to strike. When this occurred my arm seemed numb.

After some hours of work I found that noises, such as the loud tapping of a foot against a chair, proved very annoying, and if at odds with my rhythm, tended to break it and cause a decrease in speed.

I remember at several stages in the experiment a mental lag; that is, thinking of other things decreased my tapping speed. A great drop in the number of taps per min. took place when I remembered a phone call I had promised to make and under the circumstances could not fulfill. Decreases such as these will not be found on the graphs, as being aware of the score I speeded up in the subsequent minutes so that the average for five mins. covered up the deficiency. Mental lags, while having a drastic effect on the tapping rate, did not affect the rhythm of my swing of the movement of my arm, which was chiefly automatic after the first few mins. of tapping.

Another retarding factor was the losing of my rhythm in tapping. Twice during the experiment I began to assume that the tap on the left hand plate was heavier than that on the right hand one. In the attempt to correct this unbalanced swing my arm movement faltered and the swing did not cover the proper distance between the plates so as to make a proper tap. Great concentration was necessary to put an end to this retarding factor.

S3.—By experiment, I determined that by affixing my gaze midway between the two plates, there then existed a maximum of harmony between mind and body in order to get best possible results. However, by holding the head in a fixed position, my neck tended to get sore at times and cramps would set in; I was therefore forced to change the position of my head. This may have affected my general rate of speed to a minor degree.

S6.—Even after a mere five minutes my arm was apparently tiring very rapidly. I frequently missed the end plates altogether, hitting the table with considerable force. I also occasionally dropped the stylus as my fingers refused to grip it properly. This aroused in me considerable indignation and great delight in my companions.

After ten mins., although I was getting warm, my feelings improved greatly. My hand was a little stiff and blocking and misses still were frequent, giving rise to a little blue-tinted language. I was quite surprised and immensely encouraged to learn that I was hitting a lot above the average speed of my practice run. There was also a great tendency on my part to settle into a constant speed or rhythm, which had to be fought against. The movement became quite automatic and it required effort to keep my speed above the psychological level toward which the output tended.

S7.—I found that by adopting a certain method of working, I could continue longer and at a better rate. When my body was at the least tension, and my thoughts changed from time to time, then I seemed to get better results.

S9.—During the first minute or so I had considerable difficulty in developing a rhythmical stroke and no doubt wasted a great deal of energy in futile efforts to go faster. A little later I found myself tapping swiftly and lightly with little effort. However as soon as I began to think of my success I began to falter. I went no slower, but found myself missing the plates frequently. This lasted as long as I concentrated on my efforts, but my tapping soon became more mechanical and my efficiency seemed to me greater. During the first few minutes I gripped the stylus rather lightly, as one grips a pencil, and my fingers became quite cramped in a very short time. In attempting to shift the stylus to a more comfortable position, I dropped it and was rather indignant when this was (as I felt) recorded against me. From time to time I felt

restless and constantly shifted my position; moving the board, rearranging the cord, etc. Although at this time I had been going only about 20 mins., my fingers felt stiff and I was rather alarmed at the prospect of continuing this procedure for several hours.

After going for some time with considerable ease I began to feel restless again. I was dissatisfied with the position of the board, my chair, and the stylus, and felt rather nervous. I began to be afraid of breaking my rhythm and therefore concentrated my mind on ways of maintaining it. I tapped with my eyes fixed on one plate and with a conscious motion from the left hand plate to the right hand plate. The motion from the right hand plate to the left seemed unconscious and more or less reflexive. The inclination would come to me sometimes to reverse this motion and I found myself missing, and losing control of the stylus. I recall several times seeing my hand move in the direction opposite to that in which I willed it and my exasperation caused me to speak complainingly to Es. These periods did not usually last long and were followed by periods in which I felt fine and worked smoothly. I tried stamping on the floor several times to keep my mind on the rhythm and at other times found myself stamping unconsciously.

I began to block badly and at one time after four or five successive blocks felt absolutely helpless and curiously wanted to laugh. As the end of four hours began to approach my forearm became increasingly troublesome and at times I held it clear of the table to lessen the pain.

S10.—I started off in good spirits, without a glove, with my arm on the table, swinging from the elbow. My fingers began to ache within five minutes, but I knew it would pass off.

S9, one of the members of our group, had kept his elbow on the table and had had more trouble with his arm than S7 who swung his whole arm. I couldn't control the whole arm swing well, yet my arm became tired quickly with my elbow on the table, so I tried both ways alternately, trying to make a spurt as I began each method. I think that this increased the number of taps per minute but kept me from getting a steady, even swing sooner than I did.

I blocked a great deal when I tried to make spurts. I made spurts when anyone entered, when warned that I was nearing my minimum, and often at the end of a 15 min. or half hour period. I had to make an effort all the time till four or five students entered an hour and ten minutes after starting the test. This took my mind off the tapping and I realized that my arm and fingers didn't ache any more, though the fingers were sore from gripping the stylus. . . . My arm felt fine, my fingers didn't ache after putting on the glove, yet I couldn't get my score up because of blocking and missing the plate. I tried looking at the left plate but this interfered with my swing, and made it seem as if I were tapping away from rather than towards myself.

S12.—At the beginning of the test I put too much effort into gripping the stylus, which caused blockings and cramps. I noticed that in the short run or spurt, better speed was obtained by tensing the whole body, but it could not be kept up for long. I blocked frequently during the first two hours. This was caused by lack of practice, and too much concentration in hitting. I was tense, and tried to hit hard and fast, and so blocked frequently, 6 or 7 times a minute, which would cause the loss of about 40 strokes. Later on, due to practice and smoothness, blocks occurred less frequently. They always occurred more often in or directly after spurts, and as a result a better speed was obtained by the attaining of a smooth, rhythmical motion.

S13—Unlike my co-worker (S14), I encountered few blocks, those which did occur coming mostly in the first half hour of my work. They consisted in a temporary inability to move the hand holding the stylus, through the complete arc connecting the

two metal plates, so that it remained for an instant poised in mid air, and then often returned to the same plate, which was tapped twice in a row, at the expense of the other. Spurts which came in between blocks prevented the rate from falling very much. Blocking seemed to come as the result of an emotional effort to increase the speed. As long as one made such an effort coolly and unemotionally the result was generally a slight increase in taps per min., but any real intense effort into which wishful emotion had been projected frequently resulted in blocking, and hence in a decrement.

Muscular inhibitions also arose from any change in my characteristic mode of tapping. For instance, I obtained smoother and more rapid action by tapping away from me, rather than by tapping towards me, *i.e.*, by emphasizing the swing of my arm outwards, rather than the pull inwards. This action became mechanical as the experiment progressed, but even in the later stages, if I changed this rhythm my tapping became very erratic, until I switched back again by a deliberate process of heavily tapping on the left plate twice, and then beginning the original rhythm with the tap emphasized to the right.

S14.—The tapping seemed to be affected by certain mental conditions. The tapping board was so placed that one plate was closer to S than the other. There seemed to be a feeling that at one time there would be an attraction of the stylus first to one plate then to the other. When S felt that the plate nearer him was attracting the stylus more than the other he felt mentally at ease. However when there was a feeling that the farther plate was attracting the stylus, S felt a mental unrest which resulted in a loss of accuracy, speed and control.

When S suddenly blocked he would hit the one plate twice in succession. When he swung over to the other plate he would follow the same pattern or rhythm and also hit this plate twice even though he made an effort not to do so. There was an impulse to tap according to this rhythm or beat. It would require an actual effort to tap once again in the conventional manner. Also when S heard a bit of music he would have an inclination to set his tapping in time to the beat of the music. When the music was slow there was an actual inclination to slow up the tapping rate, or to speed up when livelier music was heard.

Tiredness

S1.—I was feeling fine before the experiment, but was sceptically inclined as to what the results would indicate. I was determined to go at the highest possible speed at all times as I felt that this was the only method which would show significant results.

My wrist and shoulder tired quickly after just one or two minutes as though I would soon drop in speed; in fact, I thought that I would soon stop altogether. However, after five or ten minutes the tiredness disappeared and I felt fine. I had a cigaret and noticed an immediate increase in speed. I felt as if I were working under a heavy strain and was a bit nervous and shaky. This feeling disappeared in fifteen or twenty minutes. At the end of thirty minutes I didn't relish the thought of going for five or six hours yet, and wanted to quit. I had considerable difficulty holding the stylus during the first hour.

It was quite a strain to keep going at top speed and required intense concentration to do so. I concluded that pain in the arm comes and goes periodically, accompanied by, and probably as the result of drops and increases in speed. Blocking was very much in evidence during the first hour and a half, and at the beginning of the test. Time went very quickly throughout the whole experiment except during the last 15 or 20 minutes. I found it impossible to hold top speed continuously because of minor

distractions taking my mind off my work. I felt fairly good physically and mentally at the end of three hours; though somewhat tired and indifferent.

During the second run I was a bit fed up, but was trying hard; though sleepy I was still capable of 300 taps per min. if I could concentrate on it enough. Arm was worse and I was generally tired all over.

I really concentrated during the third run and held 300 for 15 minutes, and then dropped. I felt very tired and disgusted at the end of this run, and could only hit 270 as a maximum at the end. I was not feeling well, was dizzy and groggy. This was probably due to the terrible mixture that I had for supper and the bad air. Some fresh air, cold water and coffee helped me greatly.

At the beginning of the fourth run I was quite sleepy and irritable. I did not do my best during this run as I just didn't feel like concentrating. "What's the use of tapping for hours on end just to see if I get tired" I said to myself. "Of course I get tired—I could have told you that before I started this blank experiment." However my mental attitude changed towards the end of this run, my speed increased, and I felt much better as a result of this (or vice versa?).

During the fifth run I experienced much pain at first; when told that I had fifteen minutes to the end I speeded up to 285 and was quite surprised at this speed. My mental attitude immediately changed and during the last ten minutes I hit 300 several times.

Immediately after the run I signed my name but could not control my arm at all, for it was very sore. I felt that I could have continued longer at slightly reduced speed, but saw no use in so doing.

S3.—In the last hour I believed that the Es were more tired than I was; to my mind they wanted to go home long ago. I started spurting and the shoulder became sore in a dull way at once. Though at the end of seven minutes the shoulder once more felt very good, also the whole arm. Although I knew that the end was at hand, nevertheless the thought could not pull me out of the abyss of mental fatigue into which I had fallen. Thus while I spurted at times, as the result of special effort, the minutes spent in complete indifference far exceeded the others. The last two minutes of this final run, with the goal right at hand, were spent in a special effort of intense concentration.

At the conclusion of the test except for a dull throb in the upper part of the arm and a stiff neck, also a general mental and physical fatigue, I otherwise felt fine. There were no after effects; by next morning all pain, all fatigue, all stiffness, had disappeared.

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THE PERCEPTION OF YELLOW LIGHT THROUGH RED AND GREEN BINOCULAR STIMULATIONS AS DETERMINED BY THE CONDITIONED GALVANIC RESPONSE [1]

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This experiment was devised to determine whether o would involuntarily respond in the same way to red and green as to yellow when red and green were presented simultaneously to corresponding areas of the two retinas after the manner of Hecht.

The problem is of importance in relation to the major theories of color vision which have been proposed. These theories of color vision differ as to the number of primary colors required to explain satisfactorily the 180 patches into which the spectrum is divided by the normal human eye at moderate brightness. They also differ as to the number of receptors which the eye must contain in order to account for color experiences. It is essential in the formulation of an adequate theory of color vision to determine the number of simple or primary colors for which a photochemical substance is present in the eye.

A review of the literature shows that the results obtained by the investigators of binocular color vision may be classified into the following groups. One group finds that binocular observation of colors always produces an intermediate color. Another group finds that binocular color rivalry always results without any mixing. Still another group finds that dominance, mixture or rivalry may occur, depending on the physical and physiological conditions.

Breese (1) using red and green mounted on stereograms found only rivalry. Johannsen (4) has shown that binocular fusion in general is possible, and that the results obtained in

[1] This study was carried out under the direction of Dr. M. M. White.

studies of binocular fusion are a factor of the physical and physiological conditions existing during the experiment. She did not attempt to fuse red and green binocularly, but Hecht (3) did achieve fusion. However, his method was subjective and it is possible that his findings were influenced by suggestion. The need for an objective approach to the problem is apparent.

Procedure

The apparatus devised by Hecht (3) was used. It consists of a blackened box 30 cm by 15 cm arranged so that the open end fitted against the face of the subject. The other end was closed by one or two detachable frames in which one or two Wratten filters 5 cm square were tightly fitted. Nine Wratten filters (two green filters No. 58, two blue, No. 44A, two yellow, No. 16, two red, No. 29, and one red, No. 25) equated to transmit light of about the same intensity were used.

The galvanic skin response was measured by the Wheatstone bridge method (2) with an external source of current approximately 1.5 volts. A variable resistance was kept in series with the subject at all times, always over 5,000 ohms. The subject was balanced in the Wheatstone bridge immediately before conditioning was started. The variable resistance was used to bring the beam of light to the original position to balance the subject if the light did not return to this position in two minutes.

The current for the shock was obtained from an inductorium connected with a dry cell of 1.5 volts and was conducted to the left hand of the subject by copper wires attached to copper electrodes in the form of rings on the index and third fingers.

Before conditioning all subjects were shocked to determine the minimum intensity of the current necessary to elicit a response.

The experiment was performed in adjoining rooms. An electric fan was used to circulate the air in the room where the subject sat, and to eliminate the noise made by the experimenter. All the apparatus, except the leads to the subject and the open end of the box, was placed in one room; the subject was alone in the other.

Twelve subjects were used. Four of them were used in preliminary experimentation and their results, though agreeing with subsequent findings, are not given because the technique of the experiment had not been perfected.

The O sat in a separate room facing the box, a pair of electrodes on each hand. When he had been in the room for fifteen minutes, he was balanced on the Wheatstone bridge. Then he put his head in the head rest, fixated upon the light and was shown successively in random order filters of the following colors: red (R), blue (B), green (G), yellow (Y), red and yellow (RY), red and green (RG), blue and yellow (BY). The galvanic response to each was measured in centimeters. He was then given the following directions:

> "This is an experiment in conditioning. You are to look through the opening in front of you; a light will appear from time to time in this opening. You will be shocked only with one color, whether it appears by itself or in combination with other colors regardless of position. You are not to move in your chair, and you are to keep as quiet as possible."

Subjects L and E were given these directions before the preliminary series without shock and the word 'yellow' was substituted for the word 'color.'

After the preliminary series without shock, subjects were conditioned to Y. The subject was first conditioned to Y alone by being shocked either simultaneously with the presentation of the light or one second, two seconds, or three seconds after the presentation, or at the same time that the light was turned off. The length of time of the presentations varied in order to avoid conditioning to a period of time rather than to color. When the O had been conditioned to Y alone, five presentations of Y with another color were accompanied by shock, YB, YR, and YG being used. Each of these series was followed by five presentations of a combination in which Y did not appear. After the O had given two consecutive reactions to a presentation where Y was present, series without Y (R, G, B, BG, RB) were presented until extinctionwas obtained. A single presentation of Y with shock was given after each extinction. Subject G was conditioned to B rather than to Y.

The Wratten filters were changed each time that a new color was presented either alone or in combination. During the conditioning series, in order to condition to color instead of to position, the Wratten filters were changed from right to left or vice versa, taken out and replaced again, after two or three electric shocks in any position. The large number of delays in presenting the light stimulus, and the many changes of filters, accustomed the O to the presentation of the light to such a degree that unless the adequate stimulus was present there was no response after training to the presentation of color or colors to which O had not been conditioned. Therefore, two consecutive responses of one centimeter or greater were considered evidence of conditioning to a color. Since after conditioning in the preliminary series other colors would not elicit a response, three consecutive responses of zero were considered as evidence of differentiation between these colors and Y. A response of twelve cm. or more never occurred after conditioning excepting to the adequate stimulus; responses greater than twelve cm are therefore recorded as twelve centimeters.

After the conditioned response had been established and extinction had been obtained for other colors, RG filters were presented. BG or RB was then given until extinction appeared, after which another series of RG was run.

Results

The mean galvanic responses made to various filtered lights prior to conditioning on first presentation were: R, 4.30; B, 1.8; G, 2.6; Y, 2.2; RY, 3.6; RG, 1.8; BY, 3.

Table I shows the responses to RG the first time this combination was presented, after the subject had been conditioned to Y, and the responses to other colors had been extinguished. In only three of the thirty presentations was there a failure to respond. Five of the six subjects meet the criterion set for conditioning (two consecutive responses of two centimeters or greater). Since this series followed one in which the subject had been shocked with YR it is possible that either the recency of the shock or the presentation of the shock with R in combination with Y might be responsible for the results obtained.

TABLE I

RESPONSE IN CENTIMETERS TO FIRST PRESENTATION OF RG AFTER CONDITIONING TO Y

Subject	Color RG	Number of Presentations				
		1	2	3	4	5
C		12	4	4.4	8	3.6
M		6	4	7	7	3
F		8	.2	0	0	2
L		3.6	2	7	1	.8
E		12	8	11	10	12
K		12	12	6	2	0

Both of these possibilities are eliminated in the results presented in Table II. The last series given with shock before the RG series was YB (thus eliminating both R and G) and between the shock series and RG presentation a series of RB or BG was presented. Again, only one subject failed to

TABLE II

RESPONSE IN CENTIMETERS TO PRESENTATION OF RG AFTER CONDITIONING FOLLOWING A SERIES WITHOUT SHOCK

Subject	Color RG	Number of Presentations									
		1	2	3	4	5	6	7	8	9	10
C		5.6	4.6	6.2	8	6	2	6	12	.4	0
M		7	4	2	4	4.4	5	2	2	2	4
F		.2	.4	6	0	6	.4	0	0	4	1.6
L		8	10	11	4.2	.6	8	6	12	1.2	.2
E		12	8	4	.2	10	.4	2	.2	.2	12
K		12	12	6	4	3	8	2	12	10	8

meet the criterion set for conditioning. In other words, the presentation of RG is producing the response which the subject has been conditioned to make only to Y. Each subject was given ten presentations of RG, but extinction did not appear. A single presentation of Y to subject F brought a response of 1 cm just after he had given a response of 1.6 cm to the tenth presentation of RG; this is the only subject who failed to meet the criterion for conditioning to RG and his response to Y also failed to meet it.

Table III makes possible a comparison of responses to presentations containing Y with responses to presentations not containing Y. This series was not presented to subjects M and F due to lack of time; these subjects had sat through ten fifty-minute periods, and were not asked to return for the presentations reported in this table.

TABLE III

RESPONSE IN CENTIMETERS TO PRESENTATIONS OF Y, RB, AND BG IMMEDIATELY AFTER PRESENTATION OF RG

Subject	Color	Presentations					Color	Presentations				
		1	2	3	4	5		1	2	3	4	5
C	Y	6	6	8	8	10	BG	2	0	0	0	0
L	Y	10	4	2	4	4	BG	.4	.8	0	0	0
E	BY	10	10	4	12	6	RB	0	0	0	0	0
K	Y	12	12	12	10	12	BG	6.2	1.6	0	0	0

It will be seen that Y has elicited a significant response in every case, and that presentations in which Y did not occur brought either a response of zero or a small response which was extinguished within five presentations. The strength of the conditioned response may be judged from the fact that although the subject received fifteen presentations in which Y appeared, ten with RG and five with Y, extinction did not appear.

To determine whether the response to RG might be due to the conditioning of one of these colors while conditioning to Y was taking place, and also whether the appearance of the third colored square might be sufficient to elicit a response when the subject had not been conditioned to respond to the color of this third square, a subject was conditioned to B instead of to Y. Other colors were then presented with the results given in Table IV.

Although the presentation of RG followed a presentation with shock there was no response. After the series of five presentations of BR, RG elicited a response of four centimeters after which the response was immediately extinguished. These results are in significant contrast to the responses to RG when the subject had been conditioned to Y.

TABLE IV

RESPONSE IN CENTIMETERS TO PRESENTATIONS OF VARIOUS COLORS OF A SUBJECT CONDITIONED TO B INSTEAD OF TO Y

Subject	Color	Presentations				
		1	2	3	4	5
G	RG	0	0	0	0	0
	BR	12	12	12	12	12
	RG	4	0	0	0	0
	BG	6	1	7	.4	2

Subject J was conditioned to the presentation of RG as the other subjects had been conditioned to Y or to B. The results obtained are given in Table V.

TABLE V

RESPONSE IN CENTIMETERS TO PRESENTATIONS OF VARIOUS COLORS OF A SUBJECT CONDITIONED TO RG

Subject	Color	Presentations				
		1	2	3	4	5
J	RG	4	3	2	2	2
	B	.2	0	0	0	0
	G	2	0	0	0	0
	Y	4	.4	3		
	R	0	0	0		

Although responses occur to B and G the first time each is shown they are immediately extinguished, whereas responses to RG and to Y remain through the series of three or five presentations. After being conditioned by presenting RG, the subject was asked with what color he had been shocked and he answered with 'yellow.' He was then shown a Y Wratten filter, No. 16, and he indicated that the color shown was the one with which he had been shocked. The Y perceived by the subject when one eye was stimulated by R light and the other by G light in such a way that each retina received impulses from only one color was sufficiently similar to the Y light transmitted by Wratten filter No. 16 to arouse a response by the galvanic reflex technique after conditioning to Y or vice versa.

Summary and Conclusions

The purpose of this experiment was to determine whether R and G would fuse binocularly to produce Y, when presented simultaneously to corresponding areas of the two retinas. Using electric shock as the adequate stimulus, subjects were conditioned to give a galvanic response to Y, shown singly or in combination with other colors. After this conditioned response had been established and the galvanic response to all other colors had been extinguished, R and G were exposed separately to corresponding areas of the retina of each eye. Every subject gave the conditioned galvanic reflex.

To substantiate these results, two other subjects were used. One subject was conditioned to R and G presented so that each eye was stimulated by only one color and afterwards he gave the conditioned response to Y, a reversal of the process described above. The other was conditioned to B, and afterwards he did not give the galvanic response to RG.

These results suggest that:

1. When corresponding areas of the two retinas are stimulated, one by R monochromatic transmitted light and the other by G monochromatic transmitted light Y is perceived.

2. When the retina of one eye is stimulated by R only and the other by G only the result is neither binocular rivalry nor dominance, but an immediate Y sensation.

3. Adults may be conditioned to a colored light with approximately thirty shocks with an electric current which has been pronounced by them as annoying, but not painful.

4. Conditioning established in this way is rather stable since extinction did not appear in a single subject when a shock had not been applied for at least fifteen presentations. Extinction appeared with other colors in five or less presentations.

5. Yellow need not be a primary or simple color, but may be explained by the blending in some central mechanism of the impulses carried to it by the receptors for G and R when

corresponding areas of the retinas or of the same retina are stimulated by R and G light.

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IMAGES AS CONDITIONED SENSATIONS

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The experiments described in this paper were designed to discover whether sensations could be conditioned to objective stimuli in the same automatic, mechanical, and unconscious fashion that objective responses have been conditioned in numerous experiments since Pavlov's classic ones almost a half century ago.

The plan of our experiments was briefly as follows: During deep hypnosis two stimuli, such as the ringing of a bell and a pin prick on the hand, were applied simultaneously to the subject for some half dozen pairings; before being awakened from the hypnosis, the subject was told that he would remember nothing that had happened during the hypnosis (post-hypnotic amnesia); a few minutes after being awakened, he was subjected to a succession of stimuli among which was one of the two stimuli originally applied, say the bell ringing; he was instructed to report at once if he experienced anything, visually, tactually, or in any other sense modality, besides the usual direct effects of those stimuli.

Almost without exception, imagery (conditioned sensations) was immediately reported upon presentation of the conditioned stimulus. After the bell ringing, for instance, the subject reported itching and pain on his hand, though he had no recollection of being pricked there previously or having ever heard that bell. The conditioned pain-tactual sensations appeared automatically and immediately upon the bell ringing—much to the subject's surprise.

The conditioning was performed under deep hypnosis for two reasons. (1) The concentration of attention and absence of distractions during hypnosis should facilitate the conditioning process and should lessen the likelihood of conflicting imagery which might nullify whatever conditioning

had occurred.[1] (2) A subject upon awakening from deep hypnosis has usually forgotten what happened during the trance. This forgetting can be made dependable by a suggestion of amnesia. Complete post-hypnotic amnesia—spontaneous and/or induced—was present in all our subjects and was an essential prerequisite for discovering whether imagery could be associated with a stimulus without the consciously remembered associations postulated by the classic laws of association.

These experiments, carried out as opportunity afforded during the past ten years, were performed on several subjects by several experimenters. The subjects were all college students; most of them students in General Psychology at the time of the experiment. The hypnosis was ostensibly entirely for some therapeutic or other practical non-experimental purpose, such as a class demonstration. As far as we could tell the subjects were always completely unaware of the nature of the experiment.

The experimenters were either the writer, or one of his students with sufficient theoretical and practical background in hypnosis to be entrusted with the conduct of a hypnosis demonstration before a class in General Psychology. The method of inducing hypnosis was the standard one of concentrating upon some monotonous repetitive or continuous stimulus, such as the ticking of a clock or a point of light, while suggestions of relaxation, peace, and sleep were given. Most of the subjects had been hypnotized several times before the experiment was conducted and had repeatedly shown the signs of deep hypnosis such as anesthesias, hallucinations, and post-hypnotic amnesia. Most of the experiments were conducted either in the writer's office or in a departmental partially sound-proof room.

The following protocols describe all the experimental sessions with all the subjects. The first two experiments were of a preliminary, exploratory nature.

Subject P. W. Experimenter C. L. 1929. E pricked S's hand several times with a sharp object while ringing a small bell. Post-hypnotic amnesia suggested.

[1] It will be recalled that Pavlov found it necessary to construct soundproof rooms for his experiments on conditioning and to exclude even the most minute distractions.

After waking S up and exchanging a few words with him, E rang the bell. S moved one hand toward the other that had been pricked and said he had just felt something there.

Subject C. B. Experimenter V. R. 1936. After S had been hypnotized, he was asked to look at the image of a Chinese pagoda thrown on a screen and to listen to a victrola record. After he had been awakened the victrola record was played again and he was asked to draw something—anything that came to mind. He reproduced the Chinese pagoda in some detail. When asked what made him draw the pagoda, he said he did not know. He did not remember having seen one for a couple of months. He did not remember having heard any music since he came into the room.

Subject D. G. Experimenters A. M. and C. L. 1936. After deep hypnosis had been produced, one experimenter struck a can sharply while S was tapped on the hand six or seven times with the flat side of a ruler. S jerked slightly, especially with his head, each time. Post-hypnotic amnesia was suggested and then S was awakened. After a brief conversation, S was told to report if he heard, saw, or felt any sensations while one of the E's performed various actions. E picked up various objects, stamped, banged the table, and hit various objects with the ruler, including the can. The first two times the can was hit, S jerked back his head, but on no occasion did he report any experiences other than those caused directly by the stimuli actually used. (While hypnotizing S, A. M. had suggested to him that he would hear nothing, and pay attention to nothing, but A. M.'s voice. The fact the A. M. forgot to remove this sensory limitation before proceeding with the experiment may account for the failure of conditioning to occur to an auditory stimulus.)

Subject D. G. Experimenters A. M. and C. L. 1936. After S had been hypnotized by A. M. he was poked gently in the side with a ruler and told to look at the object in front of him. The object was a nickel plated stopwatch held about eight inches from S's eyes. He was given 3–5 seconds to look at it. The combined poking and looking were repeated about six times allowing 10–15 seconds between trials. The S was then told that he would remember nothing that had happened while he was under hypnosis; he was also given some post-hypnotic suggestions concerning a class demonstration, and was awakened in the usual manner. After he was awakened A. M. told him to lie on the cot and gave him a blank card to look at. The card was placed at about the same position where the watch had been held. S was told to report anything he experienced while A. M. performed various operations. S was reminded to look at the card closely. A. M. then walked about the room and hit various objects with the ruler. Then A. M. poked S in the ribs with the ruler in the same way as had been done previously during the hypnosis. S immediately said: "Hey: wait; what the dickens!" He reported that a ring had formed on the card as soon as he had been poked. When poked in the ribs a third time he reported that the ring appeared again and that it had a black dot in the center, and was silvery. S was not able to report any other details concerning the image on the card. He was somewhat startled and puzzled at the phenomena. Later as he was walking about the room, he picked up the stop-watch box from the table and immediately exclaimed that the ring he had seen on the paper was a watch; that he was quite sure of it.

Subject D. G. Experimenters A. M. and C. L. 1936. The S was hypnotized by A. M. and the same phenomena as usual were used to make sure that S was in a deep stage of hypnosis. While C. L. snapped a cricket, A. M. pricked S on the back of the hand with an algesiometer. The stimuli were paired five times with an interval of 10–15 seconds between pairings. After being awakened, S was told to report anything he experienced while the E's did various things. As soon as C. L. snapped

the cricket S jerked his hand back from where it was lying on the chair arm and exclaimed that something had pricked him on the hand and rubbed the spot which A. M. had pricked, while S was under hypnosis. To no other stimulus that we tried, would he respond, but every time the cricket was snapped his hand jerked back and he reported feeling a pin prick.

Subject D. G. Experimenters A. M. and C. L. 1936. A. M. again hypnotized the S and then told him to pay attention to C. L. The latter held a small bottle of creosote under S's nose and asked him to smell it every time it was placed in that position. In the meantime A. M. had taken a ruler and rubbed S on the right arm with it just as C. L. held the bottle of creosote under S's nose and told him to smell it. Rubbing on the arm followed by the smell of creosote was repeated five or six times and then the S was awakened and told to report anything he might experience. A. M. then proceeded to hit or rub various objects with the ruler even rubbing the S's leg without getting any response from S; but as soon as his arm was rubbed, he sniffed the air and said that something smelled funny and that an odor had just entered the room. When he was rubbed on the arm again he said the odor was stronger but that it did not last very long. S asked A. M. if he could smell it and he said no. S seemed quite puzzled. Making it appear as accidental as possible, A. M. again rubbed S's arm and S again reported smelling some strong odor—"something like a tarred road"—'like creosote' he finally said. The smell appeared only when the right arm was rubbed; no other stimulus that A. M. tried was successful. S was very puzzled by the appearance of the odor and wanted to know what it was caused by. He said it appeared suddenly and was unmistakable but that he could not see why it appeared.

Subject J. D. Experimenter C. L. 1938. S was shown an E. S. P. card with a rectangle on it for about one minute while E tapped on a metal filing cabinet with a ruler. Shortly after being awakened S was given a blank white card and told to gaze at it fixedly and told to report if anything appeared on it. E jiggled his keys, walked up and down the room, banged a book, cleared his throat, and tapped the file with a ruler. At this last stimulus S said: "There it is; I cannot tell exactly what, but it is some kind of a mathematical figure." When asked what color it was he replied that it had a "black outline." When shown a pack of E. S. P. cards he picked the rectangle out as the figure he had seen. The figure appeared on the card each time C. L. tapped on the file, but disappeared quickly.

Subject J. D. Experimenter C. L. 1938. E pricked S about eight times with an algesiometer on the fleshy part of the right hand between the base of the thumb and index finger while tapping the top of a small can with a pencil. On awakening, S was requested to report whenever he saw, felt or otherwise experienced anything in connection with a series of stimuli. E stamped on the floor, rattled a brief case and so on finally tapping the can with a pencil. S at once scratched the previously stimulated area on his right hand with the left one and said that "it smarts and itches." He stopped scratching as soon as E stopped tapping the can and started to rub again as soon as the tapping was resumed.

Subject V. F. Experimenters D. B. and C. L. 1936. D. B. showed S a small pen and ink drawing of a fish while S moved his arm back and forth at the elbow nine or ten times. After he was awakened, S was asked to tell C. L. whenever he saw, heard, tasted, smelled, or otherwise experienced anything as he made various movements. He was then told to move his right leg, then his left leg and then to move his right arm back and forth. At that point he reported that something came into his mind but he could not tell exactly what. When given a blank piece of cardboard to look at, he saw "a fish on it, about two or three inches long and 7/8 of an inch wide at

the tail. It fades away when I stop moving my arm." The fish reappeared when the arm was moved back and forth.

Subject V. F. Experimenters D. B. and C. L. 1936. S was pricked five or six times with a victrola needle on the fleshy part of the left hand while a metal waste paper basket was tapped with a metal pencil. After S had been awakened the usual series of stimuli brought no response from him but the moment the basket was tapped he moved his left hand up quickly, looked at it, felt the fleshy part, and looked puzzled. When asked what was the matter, he replied "Feels as though it had been pricked by something small and sharp. It comes when you make that noise and disappears when you stop."

Subject V. F. Experimenter D. B. 1936. S was shown a small pen and ink drawing of a cube inside a box while moving his arm. Upon repeating this movement after waking from the hypnosis the drawing appeared very clearly as an image.

Subject V. F. Experimenter D. B. 1936. S watched E move his arm up and down and hit the table with a pencil at the down stroke. On awakening, the sight of the up and down movement was a conditioned stimulus for hearing the sound of the pencil on the table.

Subject R. F. Experimenters D. B. and C. L. 1938. A cricket was snapped about seven times as S smelt a small bottle of creosote. C. L. went through the usual repertoire of sounds, after giving S the usual instructions. When the cricket was snapped, S said "creosote," wrinkled and rubbed his nose, and turned his head away. The same results occurred when the various stimuli were repeated in a different order. There was a response to the cricket and none to the other stimuli. The S was puzzled by the odor and asked, "What does it?".

Subject F. M. Experimenters A. A. and C. L. 1939. Snapped cricket while S smelled creosote for about 20 seconds. S did not volunteer any report after any of the stimuli in the series. When questioned he said that he had tasted something when the cricket was sounded. Out of two odors he picked the creosote as the one he had tasted.

Subject F. M. Experimenters A. A. and C. L. 1939. Rang a small bell while S looked at a pair of scissors for about 15 seconds. When told to look at a blank piece of paper after awakening, S saw "a knife or sword or something like that" on the paper when the bell was rung. When four different objects were presented to him, he picked the scissors as the object whose image he had seen on the paper.

Subject L. B. Experimenter C. L. 1939. E had S smell creosote for about 15 seconds while a bell was ringing. Later when the bell was rung alone S sniffed and said "I smell something—the stuff they put in moth balls. I can't name it." When E gave him oil of lavender to smell he said "No, not that." To the smell of creosote he said, "Yes, that's it."

Subject L. B. Experimenter C. L. 1939. S looked at his glasses while the cricket was being snapped. Later the cricket did not cause any image to appear on a blank card. (S may have some difficulty seeing without glasses.)

From the protocols it is apparent that the conditioned sensations (images) were frequently accompanied by objective responses, such as a movement toward, and a scratching of, the itching hand; or a wrinkling up of the nose and sniffing movements as the creosote was imaginatively experienced. These movements were quick spontaneous responses follow-

ing immediately upon the conditioned stimulus and substantiated the subject's introspective reports. Usually, the overt movements started before the subject reported the presence of imagery.

The subject was invariably surprised and puzzled by the conditioned sensations. They came suddenly out of nowhere and vanished equally suddenly. They were entirely involuntary and automatic. After the conditioned stimulus had been repeated a number of times, the subject usually consciously realized that the imagery always followed that particular stimulus. He still wondered why that peculiar connection existed.

The conditioned sensations were frequently so intense and vivid as to be mistaken for actual sensations; the subject thought that he was really smelling an odor or that he was really being pricked on the hand by some sharp object; but the images were also fleeting and difficult to examine. They appeared and disappeared with the conditioned stimulus and if that stimulus was continued they soon grew faint. The subject could rarely name the image correctly at once: the stop watch was a silver ring with a point in the center; the creosote was a powerful penetrating odor; the rectangle was just the outline of a figure; but the image was always referred to the correct stimulus from among a number of stimuli.

Hull [2] reports the appearance of a phenomenon, similar to that described in this article, as an incidental observation in an experiment by Scott designed to discover what differences, if any, existed between the conditioning, under normal and trance conditions, of finger withdrawal by pairing buzzer and shock. "Several of these (totally amnesic) subjects . . . when stimulated by the buzzer alone—reported the feeling of having received an electric shock on the fingers. At least one of his subjects insisted that he had received a *bona fide* shock though the experimenter was positive, from testing the apparatus, that no shock could have been received."

The hypnotic state served the same purpose as the hunger drive, the soundproofing, and the exclusion of extraneous

[2] Hull, C. *Hypnosis and Suggestibility.* N. Y.: Appleton-Century. 1933. Page 401.

stimuli in general, in Pavlov's conditioned response experiments. It limited the subject's attention to the pertinent stimuli, and thereby enabled the experimenters to demonstrate a fundamental psychological principle whose functioning in everyday life is frequently obscured by the simultaneous presence of many stimuli and many responses.

Our experiments indicate that after an inadequate stimulus has been present a number of times, while an individual is experiencing certain sensations, it will by itself automatically, and without the intervention of any conscious processes, produce those sensations. An image can, therefore, be considered as a conditioned sensation.[3]

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[3] In a review of the Experimental Studies of Learning in Infants, *Psychol. Bull.*, 1935, **32**, 276–305, Wenger and Williams mention (p. 281) two attempts to condition the taste likes and dislikes of children. The reaction of children between 1½ and 3 years of age to certain stimuli, such as vinegar, was changed "from dislike to indifference and even to liking", by being paired repeatedly with a very pleasant stimulus like chocolate.

We have noticed that if an infant of about 1½ years, who has frequently eaten granulated sugar, but never pure salt, is told that salt is sugar, he will eat several small spoonfuls of the salt with apparent pleasure.

FUNCTIONAL ADAPTATION TO NEAR-VISION

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Emmetropia is usually defined as the normal condition of the ocular refractive system in which rays of light from distant objects are focused sharply upon the retina while accommodation is relaxed. Thus a state of ocular relaxation is associated, by definition, with distant fixation and with the implied assumption that relative accommodation [1] is not required to produce the condition of emmetropia. Unless a cycloplegic is used, however, it is by no means certain that relative accommodation is not functional; and under cycloplegia, the state of the ciliary muscles is not one of physiological rest since the muscles are freed from nervous control. In view of these considerations, it cannot be assumed that the muscles of the eyes of a so-called emmetropic subject are in a state of rest merely because infinity and the retina are found to be conjugate by the usual methods of ocular examination. It is the purpose of the present discussion to show that, in a state of rest assumed to be as complete as is possible during consciousness, parallel rays of light from a distant object are focused at a point anterior to the retina of the typical emmetropic subject.

The fact that a so-called emmetropic subject usually achieves maximal or near-maximal visual acuity at distance under normal seeing conditions may be attributed to the exercise of negative relative accommodation (from the position of physiological rest) which is induced by sharply-defined patterns of brightness-contrast within the visual field. In considering the meaning of the state of 'rest' in

[1] Relative accommodation: a change in the focusing of the crystalline lenses relative to that which is normal for a given state of convergence of the two eyes. When the change is in the direction of greater convexity of the crystalline lens, it is designated as *positive*.

the musculature of distant-vision it must be remembered that these muscles are of the unstriated variety and are supplied by both the sympathetic and parasympathetic nervous systems. With such a dual nerve supply, negative relative accommodation might be mediated by a decrease in parasympathetic or an increase in sympathetic nerve excitation. Thus as Cogan (1) states, "It appears that the sympathetic systems tend to adapt the eyes for relatively distant objects and as such oppose the parasympathetic system, which tends to adapt the eyes for relatively near-objects." These considerations suggest the possibility that the eyes of the so-called emmetropic adult subject may be functionally adapted to some point less than infinity when in a state of repose.

An experimental investigation of this possibility obviously involves the relaxation of accommodation and also the inhibition of negative relative accommodation. It has been shown elsewhere (2) that relative accommodation is preventable through the avoidance of an adequate stimulus for this function. However, this does not appear to be possible with the usual visual acuity test-objects and procedures since, as the threshold of resolution is approached, the critical details of the object gradually become unrecognizable although the object as a whole may still readily be perceived. Thus sufficient stimulation may be received under these conditions, to induce some degree of accommodation. If, however, a distant test-object of elementary form is brought from a subthreshold condition to the threshold of visibility by increasing its contrast, for example, while all other objects remain invisible, there can be no stimulus to accommodation until the test-object attains threshold visibility.

These visual conditions were obtained by placing suitable absorbing and diffusing filters before the eyes and gradually reducing the density of these filters until the test-object emerged from obscurity. Our experimental apparatus (3) involves, essentially, two colorless circular photographic gradient filters, precise in optical density and diffusion, which may be rotated simultaneously in front of the eyes while the subject views a suitable test-object. These gradient filters not

only alter the apparent brightness of the *entire visual field* due to absorption but also alter the contrast of objects within the visual field due to the slightly diffusing character of the photographic filters. Thus the visual field, when viewed through the filters, appeared as it would in a dense fog.

Since these filters, as used in our procedures, completely 'fogged' all details of the visual field, it was necessary to provide a separate fixational-target in order to control convergence at both the far- and near-points. The latter consisted of a bright but vaguely defined band of diffused light located in the plane of the test-object which was viewed binocularly by the subject. However, it was experimentally established that this target did *not* provide an adequate stimulus for relative accommodation. As all stimuli for accommodation were thus avoided, it was possible to alter the point of focus by means of ophthalmic lenses placed before the eyes without concomitantly stimulating the accommodative mechanism. Hence the intensity of the threshold stimulus decreased as the point of focus approached the retina, and its minimal value indicated the condition of emmetropia. When the test-object was placed at distance and gradually brought to the threshold of visibility by reducing the density of the filters, the experimental requirements of relaxed accommodation and inhibited negative relative accommodation were fulfilled. Therefore, it should be possible to detect functional adaptation to habitual near-vision tasks if the latter exists.

An experimental group of 20 subjects, including both men and women, were selected at random from technical and clerical groups for these studies. These subjects ranged in age from about 25 to 35 years and are considered as emmetropic (with corrections, if necessary) from the viewpoint of the usual ocular examinations. The data of Table I indicate the average additional dioptric power required by these subjects to obtain a minimal intensity of the threshold stimulus, or to focus the light from a distant object upon the retina, when accommodation is controlled by the techniques described.

TABLE I

These measurements were made at a fixational-distance of 20 feet and with the subjects wearing their usual corrections, if any. They are the averages of two examinations made about a month apart.

	Right Eye	Left Eye
Average for all subjects	−0.76 D.	−0.73 D.
Mean variation of mean for one subject	0.24	0.29
Probable error of general mean	0.05	0.06
Average for 12 subjects with glasses	−0.75	−0.81
Average for 8 subjects without glasses	−0.76	−0.61

It will be noted from Table I that 3/4 diopter of negative power was required to produce maximum visibility at distance when negative relative accommodation is prevented. Thus under these experimental conditions, it appears that the focus of parallel rays of light is at a point about 3/4 of a diopter anterior to the retina in the case of the typical adult emmetropic subject. Briefly, this condition may be described as a 'lead of accommodation' at the far-point. With respect to individual subjects, however, the indicated 'lead of accommodation' at the far-point varied from about 3/8 to 1 3/8 diopters. This fact minimizes the possibility that the indicated lead of accommodation is due to some systematic error in the experimental procedures.

The existence of a lead of accommodation at the far-point is supported by the fact that these same subjects were found to be emmetropic, on the average, when examined by an identical technique at the usual reading-distance as shown by the data of Table II. Thus the retina and the near-point are

TABLE II

These values indicate the additional dioptric power required to produce maximal visibility at a fixational-distance of 16 inches. Similar results were obtained at other near-points.

	Right Eye	Left Eye
Average for all subjects	+0.02 D.	+0.04 D.
Mean variation of mean for one subject	0.15	0.18
Probable error of general mean	0.02	0.02
Average for subjects with glasses	+0.02	+0.01
Average for subjects without glasses	+0.03	+0.08

conjugate when relative accommodation is inhibited in the case of the typical emmetropic adult non-presbyopic subject. However, this is not the case in distant-vision as is indicated by the data of Table I.

A lead of accommodation at the far-point and emmetropia at the near-point might be expected on teleological grounds. For example, after discounting pathological changes, there remains no indication of adaptation to the increased prevalence and importance of near-vision *unless* such adaptation has taken the form of an increased capacity for functional adaptation—a form which would in no way work to the disadvantage of the individual whose visual tasks remain principally long-range. Allowing that presbyopia is inescapable, the best imaginable compromise would give emmetropia at infinity during adolescence and emmetropia at arm's length in middle age, with distant-vision still attainable by the exercise of negative relative accommodation. This is almost precisely the average condition indicated by the data of Tables I and II.

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